# DOCUMENT RESUME

ED 244 834 SE 044 559

**AUTHOR** Stuessy, Carol Liebe

**TITLE** Correlates of Scientific Reasoning in Adolescents: Experience, Locus of Control, Age, Field Dependence-Independence, Rigidity/Flexibility, IQ, and Gender.

**PUB DATE** 84

**NOTE** 366p.; Ph.D. Dissertation, The Ohio State University.

**PUB TYPE** Dissertations/Theses - Doctoral Dissertations (041) -- Reports - Research/Technical (143)

**EDRS PRICE** MF01/PC15 Plus Postage.

**DESCRIPTORS** Abstract Reasoning; Adolescents; Age; Cognitive Processes; *Field Dependence Independence; Intellectual Development; Intelligence Quotient; *Locus of Control; *Logical Thinking; *Predictor Variables; Science Education; Secondary Education; *Secondary School Science; Sex; *Student Characteristics; Student Experience

**IDENTIFIERS** Science Education Research

**ABSTRACT**

A model for the development of scientific reasoning in adolescents was formulated largely upon the basis of Piagetian theory. Included as potential determinants of scientific reasoning were experience, age, locus of control, field independence-dependence (FID), rigidity/flexibility, intelligence quotient (IQ), and sex. Causal relationships between these variables were hypothesized a priori with strong theoretical, heuristic, and empirical support. Data collected from middle school (N=106) and high school (N=96) students were used to test the hypothesized model by path analyses. Multiple regressions were performed according to path analytic methods to acquire standardized beta weights for determinant variables. These beta values were used as path coefficients for each of the posited relationships. Significant path coefficients resulted for these variables and scientific reasoning: age; IQ; FID; and experience. Age and IQ were stronger determinants of scientific reasoning than were FID and experience. Indirect effects of locus of control on scientific reasoning through FID also was obtained. Paths involving sex and rigidity/flexibility were not significant. The revised model included significant paths which explained 61 percent of the variance in scientific reasoning. (Author/JN)

***********************************************************************

* Reproductions supplied by EDRS are the best that can be made *

* from the original document. *

***********************************************************************

ED244834

U.S. DEPARTMENT OF EDUCATION
NATIONAL INSTITUTE OF EDUCATION
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

This document has been reproduced as received from the person or organization originating it.
Minor changes have been made to improve reproduction quality.

- Points of view or opinions stated in this document do not necessarily represent official NIE position or policy.

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY
Carol Stuessy
TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

# CORRELATES OF SCIENTIFIC REASONING IN ADOLESCENTS: EXPERIENCE, LOCUS OF CONTROL, AGE, FIELD DEPENDENCE-INDEPENDENCE, RIGIDITY/FLEXIBILITY, IQ, AND GENDER

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of the Ohio State University

By

Carol Sue Liebe Stuessy, B.A., B.S.

***

The Ohio State University
1984

Reading Committee:

Stanley L. Helgeson
Philip M. Clark
Arthur L. White

Approved By

Stanley L. Helgeson
Adviser
Department of
Educational Theory
and Practice

SE044559

# CORRELATES OF SCIENTIFIC REASONING IN ADOLESCENTS: EXPERIENCE, LOCUS OF CONTROL, AGE, FIELD DEPENDENCE-INDEPENDENCE, RIGIDITY/FLEXIBILITY, IQ, AND GENDER

BY

Carol Liebe Stuessy, Ph.D.

The Ohio State University, 1984

Professor Stanley L. Helgeson, Adviser

A model for the development of Scientific Reasoning in adolescents was formulated largely upon the basis of Piagetian theory. Included as potential determinants of Scientific Reasoning were Experience, Age, Locus of Control, Field Dependence-Independence, Rigidity/Flexibility, IQ, and Gender. Causal relationships between these variables were hypothesized a priori with strong theoretical, heuristic, and empirical support.

Variables were measured by the following instruments: Cognitive and Recreational Activity Scale (Experience); Intellectual Achievement Responsibility Questionnaire (Locus of Control); Concealed Figures Test (Field Dependence-Independence); Breskin's Rigidity Test (Rigidity/Flexibility); Short Form Test of Academic Aptitude (IQ). These instruments and a background data sheet were

SE044559

administered to middle school ($n$=106) and high school ($n$=96) students from an upper middle-class suburb of Columbus, Ohio.

Data collected from these students were used to test the hypothesized model for Scientific Reasoning by path analysis. Multiple regressions were performed according to path analytic methods in order to acquire standardized beta weights for determinant variables. These beta values were used as path coefficients for each of the posited relationships.

Significant ($p < 0.05$) path coefficients resulted for these variables and Scientific Reasoning: Age, IQ, Field Dependence-Independence, and Experience. Age and IQ (with path coefficients of 0.54 and 0.49, respectively), were stronger determinants of Scientific Reasoning than were Field Dependence-Independence (0.15) and Experience (0.11). Indirect effects of Locus of Control (0.28) on Scientific Reasoning through Field Dependence also was obtained. Paths involving Gender and Rigidity/Flexibility were not significant. The revised model included significant paths, which explained 61 percent of the variance in Scientific Reasoning.

To Susan Kyser

# ACKNOWLEDGMENTS

The ideas presented herein are synthesized from many sources. I am indebted to many people who have contributed their ideas, their help, and their encouragement to this project. Essential to the construction of the theoretical framework for this study were early discussions with Margo Baldwin and Dr. James E. Gebhart. They started me in the right direction and helped me to define the universe of the study. Seminars and discussions with Dr. Philip M. Clark, who served on the dissertation committee, were valuable in the initial identification of probable personological variables affecting the development of scientific reasoning. Dr. Arthur L. White, who also served on the dissertation committee, initially suggested path analysis and subsequently evaluated the statistical methodology employed in testing the hypotheses posited in the research. My adviser, Dr. Stanley L. Helgeson, was helpful in many ways, but especially in his insistence on clarity at all times during the processes of studying for the generals examination as well as during the stages of the dissertation research. As well, Dr. Helgeson's helpful suggestions aided me in my struggle to develop a personal philosophy regarding the role of science education within the broader context of the scientific enterprise. This philosophy is reflected in part within the contents of this dissertation.

A special note of appreciation is due Dr. John S. Monk for his invaluable advice, time, and effort in helping me with my research. John was consistently there whenever needed, for whatever task, and I am deeply grateful for his advice and support throughout the course of the project.

I also wish to thank Dr. Gary L. Floyd for serving as mentor, teacher, colleague, and friend. Dr. Floyd has freely given of his time, knowledge, understanding, and advice throughout my years as a graduate student at Ohio State. As well, my experience with collaborative scientific research in his laboratory was an opportunity I will value for a lifetime, truly the highlight of my graduate school experience.

Finally, my deepest appreciation goes to my family and the many friends who have shared with me the joys and the frustrations of writing a dissertation. I wish to thank in particular my mother, Betty Sue Liebe, and my two small children, Mary and Alan, for their gifts of unconditional love, trust, and patience. These loved ones provide meaning at a very personal level for the completion of this project.

# VITA

| | |
|---|---|
| March 30, 1945. . . . . . | Born - Hollis, Oklahoma |
| 1968 . . . . . . . . . . . | B. A., Biology, The University of Texas at Austin; Austin, Texas |
| 1969 . . . . . . . . . . . | B. Sc. Ed., The Ohio State University, Columbus, Ohio |
| 1969-1971 . . . . . . . . . | High School Biology Teacher, Worthington, Ohio |
| 1972-1976 . . . . . . . . . | Middle School Science Teacher, Worthington, Ohio |
| 1980-1981 . . . . . . . . . | Graduate Research Associate, ERIC Clearinghouse for Science, Mathematics, and Environmental Education, Ohio State University |
| 1981-1982 . . . . . . . . . | Graduate Teaching Assistant, Department of Science Education, Ohio State University |
| Summers 1982 and 1983 . . | Research Associate, Phycological Research, Department of Botany, Ohio State University |
| 1982-1983 . . . . . . . . . | Middle School Science Teacher, Worthington, Ohio |
| 1983-1984 . . . . . . . . . | Resource Teacher for Gifted and Academically Talented Students, Worthington, Ohio |

## Publications

Stuessy, C. L., G. L. Floyd, and C. J. O'Kelly. 1982. Fine structural studies on the quadriflagellate zoospores of an Enteromorpha species (Ulvaceae, Chlorophyta) collected in fresh water. Ohio Journal of Science 82 (Abstracts): 17.

Stuessy, C. L., G. L. Floyd, and C. J. O'Kelly. 1983. Fine structure of the zoospores of an Enteromorpha species collected from fresh water. British Journal of Phycology 18: 249-257.

## Workshops and/or Presented Papers

"Utilization of data bases in teaching college biology," a workshop presented for members of the Midwest College Biology Teachers' Association at the Annual Meeting, Decatur, Illinois, Fall 1980.

"Fine structural studies on the quadriflagellate zoospores of an Enteromorpha species (Ulvaceae, Chlorophyta) collected in fresh water," a paper presented at the Annual Meeting of the Ohio Academy of Sciences, Columbus, Ohio, Spring 1982. [Research results in collaboration with G. L. Floyd and C. J. O'Kelly, presented by C. L. S.]

## Fields of Study

Major Field: Science Education

Studies in Biology (Algal Phylogeny and Cellular Ultrastructure)

Studies in Research Design and Methodology

Studies in Science Education at the College Level

# TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS . . . . . . . . . . . . . . . . . . . . iii

VITA . . . . . . . . . . . . . . . . . . . . . . . . . . v

LIST OF TABLES . . . . . . . . . . . . . . . . . . . . . xx

LIST OF FIGURES . . . . . . . . . . . . . . . . . . . . xxiv

CHAPTER

I. INTRODUCTION . . . . . . . . . . . . . . . . . . . 1

Need for the Study . . . . . . . . . . . . . . . . 3

Purpose of the Research . . . . . . . . . . . . . 9

Problem Statement. . . . . . . . . . . . . . . . . 9

Research Hypotheses . . . . . . . . . . . . . . . 10

Rationale . . . . . . . . . . . . . . . . . . . . 14

Rationality and Scientific Reasoning. . . . 14

Factors Affecting Scientific Reasoning. . . 14

Assumptions of This Study. . . . . . . . . . . . . 15

Social Transmission and Locus of Control. 15

Equilibration and Rigidity/Flexibility. . 15

Aptitude and Field Dependence-Independence . . . . . . . . . . . . . . . 19

Definition of Key Terms . . . . . . . . . . . . 19

TABLE OF CONTENTS - continued Page

Variables Considered in This Study . . . . . . 22
- Scientific Reasoning Ability. . . . . . . 22
- Experiential Variable . . . . . . . . . . 22
- Social Transmission Variable. . . . . . . 22
- Maturational Variable . . . . . . . . . . 24
- Aptitude Variable . . . . . . . . . . . . 24
- Equilibration Variable. . . . . . . . . . 24
- IQ and Gender . . . . . . . . . . . . . . 24

Limitations. . . . . . . . . . . . . . . . . . 24

Summary Statement of Chapter One . . . . . . . 25

II. REVIEW OF THE LITERATURE . . . . . . . . . . . 27

Section I: Introduction . . . . . . . . . . . 27
- Rational Thought. . . . . . . . . . . . . 28
- Scientific Reasoning. . . . . . . . . . . 31
- The Relationship of Scientific Reasoning To the Development of Formal Operational Thought . . . . . . . . . . . . . . . . . 33

Section II: Factors Affecting the Development of Scientific Reasoning Abilities 38
- Introduction. . . . . . . . . . . . . . . 38
  - Experience, Social Transmission, and Maturation - The Original Piagetian Variables. . . . . . . . . . . . . 38
  - Aptitude and Equilibration - Factors of Importance in Adolescence . . . . 40
  - IQ and Gender - Non-Piagetian Variables. . . . . . . . . . . . . 43

TABLE OF CONTENTS - continued                                        Page

A. Experience. . . . . . . . . . . . . . . 45

  Theoretical Considerations . . . . . 45

  Experience and Scientific Reasoning 47

  The Cognitive and Recreational Activity Scale as a Measure of Experience . . . . . . . . . . . . . . 50

  Experience and Field Dependence-Independence . . . . . . . . . . . . 51

  Hypothesized Relationships Concerning Experience as an Independent Variable . . . . . . . . 52

B. Locus of Control. . . . . . . . . . . 53

  Theoretical Considerations . . . . . 53

  Development of the Intellectual Achievement Responsibility Questionnaire as a Measure of Locus of Control . . . . . . . . . . 57

  Locus of Control and Field Dependence-Independence. . . . . . . 58

  Locus of Control and Scientific Reasoning. . . . . . . . . . . . . . . 62

  Hypothesized Relationships Concerning Locus of Control as an Independent Variable . . . . . . . . 64

C. Age . . . . . . . . . . . . . . . . . 64

  Age and Experience . . . . . . . . . 64

  Age and Rigidity/Flexibility . . . . 66

  Age and Scientific Reasoning . . . . 67

  Hypothesized Relationships Concerning Age As an Independent Variable . . . . . . . . . . . . . . 71

TABLE OF CONTENTS - continued Page

D. Field Dependence-Independence . . . . 73

Theoretical Considerations . . . . . 73

The Concealed Figures Test as a Measure of Field Dependence-Independence. . . . . . . 75

Field Dependence-Independence and Scientific Reasoning Ability . . . . 75

Hypothesized Relationships Concerning Field Dependence-Independence as an Independent Variable . . . . . . . . 78

E. Flexibility/Rigidity. . . . . . . . . 80

Theoretical Considerations . . . . . 80

The Breskin Rigidity Test as a Measure of Rigidity/Flexibility. . . 84

Rigidity/Flexibility and Field Dependence-Independence. . . . . . . 87

Rigidity and Scientific Reasoning. . 88

Hypothesized Relationships Concerning Flexibility/Rigidity As An Independent Variable . . . . . 89

F. IQ. . . . . . . . . . . . . . . . . . 91

Theoretical Considerations Regarding Intelligence, Ability to Learn, and IQ . . . . . . . . . . 91

IQ and Scientific Reasoning. . . . . 98

The Short Form Test of Academic Aptitude As a Measure of IQ. . . . . 100

Hypothesized Relationships Regarding IQ As an Independent Variable . . . . . . . . . . . . . . 102

G. Gender. . . . . . . . . . . . . . . . . . 104
Theoretical Considerations . . . . . 104
Gender and Locus of Control. . . . . 106
Gender and Experience. . . . . . . . 107
Gender and Field Dependence-Independence . . . . . . . . . . . . 108
Hypothesized Relationships Concerning Gender As an Independent Variable . . . . . . . . . 111
Section III: Results of the Pilot Project for This Study . . . . . . . . . 113
Reliabilities of Instruments. . . . . . . 113
Results of the Pilot Study. . . . . . . . 114
Discussion. . . . . . . . . . . . . . . . 118
Implications of the Pilot Study Results for the Current Research. . . . . . . . . 121
Section IV: Path Analysis . . . . . . . . . . 123
Theory of Path Analysis . . . . . . . . . 123
The Model . . . . . . . . . . . . . . . . 124
Variables in the Path Model . . . . . . . 125
The Path Diagram. . . . . . . . . . . . . 126
Path Coefficients . . . . . . . . . . . . 127
Analysis of the Causal Model. . . . . . . 127
Interpreting the Path Coefficients. . . . 130
Summary Statement of Chapter Two . . . . . . . 132

III. METHODOLOGY. . . . . . . . . . . . . . . . . . . . 133

Research Design. . . . . . . . . . . . . . . . . . . 133

Subjects . . . . . . . . . . . . . . . . . . . . . . 134

Administration Techniques. . . . . . . . . . . . . . 135

Instrumentation. . . . . . . . . . . . . . . . . . . 138

Instruments . . . . . . . . . . . . . . . . . 138

Instrument Analysis . . . . . . . . . . . . . 142

Statistical Analyses . . . . . . . . . . . . . . . . 145

Preliminary Analyses. . . . . . . . . . . . . 145

Correlational Analyses: Hypothesis I . . . . 145

Comparison of Correlation Coefficients: Hypothesis II. . . . . . . . 146

Regression Analyses: Hypothesis III. . . . . 146

Factors Jeopardizing Validity of The Study . . . . . 147

Concerns of Internal Validity . . . . . . . . 148

Summary Statement of Chapter Three . . . . . . . . . 153

IV. RESULTS. . . . . . . . . . . . . . . . . . . . . . 154

Testing Hypothesis I . . . . . . . . . . . . . . . . 154

Hypothesis I. . . . . . . . . . . . . . . . . 140

Hypothesis I-a. . . . . . . . . . . . . . . . 156

Hypothesis I-b. . . . . . . . . . . . . . . . 156

Hypothesis I-c. . . . . . . . . . . . . . . . 158

Hypothesis I-d. . . . . . . . . . . . . . . . 158

Hypothesis I-e. . . . . . . . . . . . . . . . 158

Hypothesis I-f. . . . . . . . . . . . . . . . 158

Hypothesis I-g. . . . . . . . . . . . . . . . 159

Hypothesis I-h. . . . . . . . . . . . . . . . 159

Hypothesis I-i. . . . . . . . . . . . . . . . [illegible]

Hypothesis I-j. . . . . . . . . . . . . . . . 160

Hypothesis I-k. . . . . . . . . . . . . . . . 160

Hypothesis I-l. . . . . . . . . . . . . . . . 160

Hypothesis I-m. . . . . . . . . . . . . . . . 161

Hypothesis I-n. . . . . . . . . . . . . . . . 161

Summary of Hypothesis I Findings. . . . . 161

Testing Hypothesis II. . . . . . . . . . . . . . 162

Hypothesis II . . . . . . . . . . . . . . . . 165

Hypothesis II-a . . . . . . . . . . . . . . . 165

Hypothesis II-b . . . . . . . . . . . . . . . 166

Hypothesis II-c . . . . . . . . . . . . . . . 166

Hypothesis II-d . . . . . . . . . . . . . . . 166

Summary of Hypothesis II Findings . . . . 167

Testing Hypothesis III . . . . . . . . . . . . . 168

Hypothesis III. . . . . . . . . . . . . . . . 169

Calculation for Path Coefficient P84: Experience to Scientific Reasoning. . . . 171

Calculation of Path Coefficient P74: Experience to Field Dependence-Independence. . . . . . . . . . . . . . . . 172

Calculation of Path Coefficient P85: Locus of Control to Scientific Reasoning. 173

TABLE OF CONTENTS - continued Page

Calculation of Path Coefficient P75: Locus of Control to Field Dependence-Independence. . . . . . . . . . . . . . . . 174

Calculation of Path Coefficient P41: Age to Experience . . . . . . . . . . . . . . 175

Calculation of Path Coefficient P61: Age to Rigidity/Flexibility . . . . . . . . 175

Calculation of Path Coefficient P81: Age to Scientific Reasoning . . . . . . . . 176

Calculation of Path Coefficient P87: Field Dependence-Independence to Scientific Reasoning. . . . . . . . . . . . 177

Calculation of Path Coefficient P76: Rigidity/Flexibility to Field Dependence-Independence . . . . . . . . . . 178

Calculation of Path Coefficient P86: Rigidity/Flexibility to Scientific Reasoning . . . . . . . . . . . . . . . . . 179

Calculation of Path Coefficient P83: IQ to Scientific Reasoning. . . . . . . . . 180

Calculation of Path Coefficient P52: Gender to Locus of Control. . . . . . . . . 181

Calculation of Path Coefficient P42: Gender to Experience. . . . . . . . . . . . 182

Calculation of Path Coefficient P72: Gender to Field Dependence-Independence. . . . . . . . . . . . . . . . 183

Summary of Initial Calculations for Coefficients. . . . . . . . . . . . . . . . 184

Calculation of the Revised Path Coefficient P84: Experience to Scientific Reasoning. . . . . . . . . . . . 187

Calculation of Revised Path Coefficient P81: Age to Scientific Reasoning . . . . . . . . . . . . . . . . . 189

TABLE OF CONTENTS - continued Page

Calculation of Revised Path Coefficient P83: IQ to Scientific Reasoning. . . . . . . . . . . . 190

Calculation of Revised Path Coefficient P87: Field Dependence-Independence to Scientific Reasoning. . . 191

Calculation of Revised Path Coefficient P75: Locus of Control to Field Dependence-Independence. . . . . 192

Summary of Procedures Resulting in Revised Path Coefficients . . . . . . . . . 193

Post Hoc Theory Modification. . . . . . . . 194

Summary of Hypothesis III Findings. . . . 200

Summary of Results Regarding the Testing of Hypotheses I, II, and III . . . . . 202

Findings Regarding Experience . . . . . . 204

Findings Regarding Locus of Control . . . 206

Findings Regarding Age. . . . . . . . . . 206

Findings Regarding Field Dependence-Independence. . . . . . . . . . . . . . . . . 207

Findings Regarding Rigidity/Flexibility . 208

Findings Regarding IQ . . . . . . . . . . 209

Findings Regarding Gender . . . . . . . . 209

Findings Regarding Scientific Reasoning . 210

Summary Statement of Chapter Four. . . . . . . 211

TABLE OF CONTENTS - continued

Page

V. DISCUSSION OF THE RESULTS: CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS. . . . . . . 219

Section I: Discussion, Conclusions, Implications and Recommendations Regarding Individual Variables Examined Within the Research . . . 221

Philosophical Basis of the Research. 221

A. Experience. . . . . . . . . . . . . . . 224

Overview of the Variable . . . . . . 224

Discussion of Hypotheses . . . . . . 225

Discussion of Results. . . . . . . . 226

Conclusions. . . . . . . . . . . . . 229

Implications . . . . . . . . . . . . 230

Recommendations. . . . . . . . . . . 230

B. Locus of Control. . . . . . . . . . . 232

Overview of the Variable . . . . . . 232

Discussion of Hypotheses . . . . . . 233

Discussion of Results. . . . . . . . 233

Conclusions. . . . . . . . . . . . . 235

Implications . . . . . . . . . . . . 236

Recommendations. . . . . . . . . . . 239

C. Age . . . . . . . . . . . . . . . . . . . 241
Overview of the Variable . . . . . . . 241
Discussion of Hypotheses . . . . . . . 241
Discussion of Results. . . . . . . . . 242
Conclusions. . . . . . . . . . . . . . 246
Implications . . . . . . . . . . . . . 247
Recommendations. . . . . . . . . . . . 249

D. Field Dependence-Independence . . . . 251
Overview of the Variable . . . . . . . 251
Discussion of Hypotheses . . . . . . . 253
Discussion of Results. . . . . . . . . 254
Conclusions. . . . . . . . . . . . . . 257
Implications . . . . . . . . . . . . . 258
Recommendations. . . . . . . . . . . . 260

E. Rigidity/Flexibility. . . . . . . . . . 261
Overview of the Variable . . . . . . . 261
Discussion of Hypotheses . . . . . . . 263
Discussion of Results. . . . . . . . . 263
Conclusions. . . . . . . . . . . . . . 264
Implications . . . . . . . . . . . . . 265
Recommendations. . . . . . . . . . . . 267

TABLE OF CONTENTS - continued Page

F. IQ. . . . . . . . . . . . . . . . . . . . 268
Overview of the Variable . . . . . . 268
Discussion of Hypotheses . . . . . . 269
Discussion of Results. . . . . . . . 270
Conclusions. . . . . . . . . . . . . 270
Implications . . . . . . . . . . . . 271
Recommendations. . . . . . . . . . . 272
G. Gender. . . . . . . . . . . . . . . . . 273
Overview of the Variable . . . . . . 273
Discussion of Hypotheses . . . . . . 274
Discussion of Results. . . . . . . . 274
Conclusions. . . . . . . . . . . . . 277
Implications . . . . . . . . . . . . 277
Recommendations. . . . . . . . . . . 278
Section II. Discussion, Conclusions, Implications, and Recommendations Regarding Significant Findings of the Research . . . . . . . . . 279
Discussion of the Significant Findings of the Research . . . . . . . . . . . . . 279
Implications Regarding Significant Findings of the Study . . . . . . . . . . 283
Implications for the Role of the Science Teacher. . . . . . . . . . . 284
Implications for Science Classroom Management . . . . . . . . 28[illegible]
Implications for Science Content . . 289

Recommendations for Further Study Based Upon the Significant Findings of the Study. . . . . . . . . . . . . . . . . 292

Summary Statement of Chapter Five. . . . . . . . 298

APPENDIXES

A. Rating Sheet for Items Within the Cognitive and Recreational Activity Scale . . . . . . . . . . . . . . . . . . . 301

B. Cognitive and Recreational Activity Scale . . . . . . . . . . . . . . . . . . . 303

C. Breskin's Rigidity Test . . . . . . . . . . 305

D. Intellectual and Academic Responsibility Questionnaire. . . . . . . . 307

E. Procedures and Answer Sheet for the Scientific Reasoning Test . . . . . . . . . 311

BIBLIOGRAPHY . . . . . . . . . . . . . . . . . . . . . 328

# LIST OF TABLES

Table Page

1-1. Variables Examined In the Research With Their Corresponding Constructs and Instruments. . . . . . . . . . . . . . . 23

2-1. Reliabilities, Means, Standard Deviations, and Ranges for Pilot Project Variables . . 115

2-2. Correlation Matrix of All Variables Considered in the Pilot Study. . . . . . . 116

2-3. Statistics for Regressions of Locus of Control, Age, Field Dependence-Independence, Rigidity/Flexibility, IQ, and Gender on Scientific Reasoning for Students Participating in the Pilot Study. . . . . . . . . . . . . . . . . . . 117

3-1. Demographic Data Regarding Total Subjects and Subjects By Age Groups . . . . . . . . 136

3-2. Testing Schedule for Middle School and High School Classes Participating in the Study. . . . . . . . . . . . . . . . . . 138

3-3. Reliabilities, Means, Standard Deviations, and Ranges for Instruments and Variables for All Subjects . . . . . . . . . . . . . . 143

3-4. Reliabilities, Means, and Standard Deviations for Instruments and Variables by Age Group . . . . . . . . . . . . . . . . 144

4-1. Correlation Matrix for All Variables Considered in the Study. . . . . . . . . . 157

4-2. Correlation Coefficients, Corresponding Z Coefficients, and N's for Younger and Older Adolescent Samples, With Computed Differences in Z and Corresponding Levels of Significance. . . . . . . . . . . . . . 164

LIST OF TABLES - continued Page

4-3. Multiple Regression to Determine the Path Coefficient P84 (From Experience to Scientific Reasoning) . . . . . . . . . 171

4-4. Multiple Regression to Determine the Path Coefficient P74 (From Experience to Field Dependence-Independence). . . . . 172

4-5. Multiple Regression to Determine the Path Coefficient P85 (From Locus of Control to Scientific Reasoning) . . . . . 173

4-6. Multiple Regression to Determine the Path Coefficient P75 (From Locus of Control to Field Dependence-Independence). . . . . . . . . . . . . . . . 174

4-7. Multiple Regression to Determine the Path Coefficient P41 (From Age to Experience). . . . . . . . . . . . . . . . 175

4-8. Simple Regression to Determine the Path Coefficient P61 (From Age to Rigidity/Flexibility). . . . . . . . . . . 176

4-9. Multiple Regression to Determine the Path Coefficient P81 (From Age to Scientific Reasoning). . . . . . . . . . . 177

4-10. Multiple Regression to Determine the Path Coefficient P87 (From Field Dependence-Independence to Scientific Reasoning) . . . . . . . . . . . . . . . . . 178

4-11. Multiple Regression to Determine the Path Coefficient P76 (From Rigidity/Flexibility to Field Dependence-Independence). . . . . . . . . . . . . . . . 179

4-12. Multiple Regression to Determine the Path Coefficient P86 (From Rigidity/Flexibility to Scientific Reasoning) . . . 180

4-13. Multiple Regression to Determine the Path Coefficient P83 (From IQ to Scientific Reasoning). . . . . . . . . . . 181

LIST OF TABLES - continued

Page

4-14. Simple Regression to Determine the Path Coefficient P52 (From Gender to Locus of Control). . . . . . . . . . . . . . 182

4-15. Multiple Regression to Determine the Path Coefficient P42 (From Gender to Experience). . . . . . . . . . . . . . . . . 182

4-16. Multiple Regression to Determine the Path Coefficient P72 (From Gender to Field Dependence-Independence) . . . . . . 183

4-17. Summary of Regression from Which Original Path Coefficients Were Obtained For Testing the Causal Model of Scientific Reasoning . . . . . . . . . . . 186

4-18. Multiple Regression to Determine the Revised Path Coefficient P84 (From Experience to Scientific Reasoning). . . . 189

4-19. Multiple Regression to Determine the Revised Path Coefficient P81 (From Age to Scientific Reasoning) . . . . . . . 190

4-20. Multiple Regression to Determine the Revised Path Coefficient P83 (From IQ to Scientific Reasoning). . . . . . . . 191

4-21. Multiple Regression to Determine the Revised Path Coefficient P87 (From Field Dependence-Independence to Scientific Reasoning). . . . . . . . . . . 192

4-22. Simple Regression to Determine the Revised Path Coefficient P75 (From Locus of Control to Field Dependence-Independence). . . . . . . . . . . . . . . . 193

4-23. Summary of Regressions From Which Revised Path Coefficients Were Obtained for the Simplified Causal Model for Scientific Reasoning . . . . . . 194

4-24. Post Hoc Multiple Regression to Determine the Path Coefficient P52 (From Gender to Locus of Control). . . 198

LIST OF TABLES - continued Page

4-25. Post Hoc Multiple Regression to Determine the Path Coefficient P54 (From Experience to Locus of Control) . . . . . . . . . . . . . . . . . . 199

4-26. Summary Table of the Significant Results of the Study . . . . . . . . . . . . 205

4-27. Summary of Significant Correlational Data Regarding All Variables in the Study. . . . . . . . . . . . . . . . . . . . 212

4-28. Summary of Significant Regression Data Regarding Variables in the Final Model for Scientific Reasoning . . . . . . . . . . 213

4-29. Simple and Multiple Squared Coefficients of Correlation for Paths in the Revised Model for Scientific Reasoning . . . . . . 214

## LIST OF FIGURES

Figure Page

1-1. A causal model displaying hypothesized relationships between variables which may ultimately affect scientific reasoning ability in adolescents . . . . . . 13

2-1. A causal model for scientific reasoning ability highlighting the proposed relationships between experience (as the independent variable) and the dependent variables of field dependence-independence and scientific reasoning ability. . . . . . . . . . . . . . . . . . . . 54

2-2. A causal model for scientific reasoning ability highlighting the proposed relationships between locus of control (as the independent variable) and the dependent variables of field dependence-independence and scientific reasoning ability. . . . . . . . . . . . . . . . . . . . 65

2-3. A causal model for scientific reasoning ability highlighting the proposed relationships between age (as the independent variable) and the dependent variables of experience, rigidity/flexibility and scientific reasoning ability. . . . . . . . . . . . . . . . . . . . 72

2-4. A causal model for scientific reasoning ability highlighting the proposed relationships between field dependence-independence (as the independent variable) and scientific reasoning ability. . . . . . . . . . . . . . . . . . . . 79

LIST OF FIGURES - continued

Page

2-5. A causal model for scientific reasoning ability highlighting the proposed relationships between rigidity/ flexibility and the variables of field dependence-independence and scientific reasoning ability . . . . . . . . 90

2-6. A causal model for scientific reasoning ability highlighting the proposed relationships between IQ (as the independent variable) and scientific reasoning ability. . . . . . . . . . . . . . . 103

2-7. A causal model for scientific reasoning ability highlighting the proposed relationships between gender (as the independent variable) and the variables of locus of control, experience, and field dependence-independence. . . . . . . . 112

2-8. A causal model for scientific reasoning ability highlighting paths between pairs of variables which were suggested by data gathered during the pilot project . . . 122

2-9. A causal model displaying notations used to designate relationships between variables which ultimately affect scientific reasoning . . . . . . . . . . . . . 128

4-1. A causal model for Scientific Reasoning displaying hypothesized paths between variables which were tested by path analysis techniques. . . . . . . . . . . . . 170

4-2. A causal model displaying path coefficients and their corresponding standard errors (in parentheses) obtained from regression analyses. . . . . . 185

4-3. A simplified causal model displaying the statistically significant ($p < 0.05$) relationships which resulted from the testing of the postulated model of HypothesisIII. . . . . . . . . . . . . . . . 188

LIST OF FIGURES - continued Page

4-4. A causal model modified post hoc to include a hypothesized relationship between Experience and Locus of Control (P54). . . . . . . . . . . . . . . . . . . . . . . . 196

4-5. The final revised causal model displaying significant ($p < 0.05$) relationships between variables shown to have direct and/or indirect effects on Scientific Reasoning. . . . . . . . . . . . . . . . . . . 201

5-1. The final revised causal model displaying significant ($p < 0.05$) relationships between variables shown to have direct and/or indirect effects on Scientific Reasoning. . . . . . . . . . . . . . . . . . . 281

# CHAPTER ONE

## INTRODUCTION

> The unique and primal characteristic of man is his mind --its capacity to function as a generalized problem-solving system--the critical edge of its operation being man's capacity for conscious choice. Ultimately, as man chooses, so he lives or dies as a species..... The role of education is to cultivate the capacity of the species to survive and thrive through the fitting use of its primal instrument, the human mind. (Ross L. Mooney, 1980, pp. 307-308)

As formidable as the task appears, there can be little doubt that the over-riding goal of education today is to lead citizens to become the healthiest people they can possibly be, to comprise a society of individuals who will perpetuate the human species, bestowing them with the skills to maintain a high quality of life even in the midst of the stresses and ambiguities imposed by a rapidly changing, fast-moving, technological society (Educational Policies Commission, 1961; Harms and Yager, 1980).

The long standing commitment of science educators to the promotion of scientific literacy of the public has never been more important than in addressing the problems associated with today's rapidly changing society. Scientific literacy implies that citizens understand the nature of science, that they possess mastery of basic scientific concepts, that they exhibit scientific attitudes, and that they use the methodology of science in everyday life (Showalter, Cox, and Holobinko, 1974) to search for understanding and meanings in the realm of their existence (Bronowski, 1951).

The methodology of science involves the fusion of the older methodologies of fact-finding and rational thinking (Bronowski, 1951; Cohen, 1953). The concern of the present research is with the rational thinking involved in scientific methodology, hereafter called "scientific reasoning." Scientific reasoning, as used in this study, is used to denote consistent, logical thought patterns which are employed during the process of scientific inquiry that enable individuals to propose relationships between observed phenomena; to design experiments which test hypotheses concerning the proposed relationships; to determine all possible alternatives and outcomes; to consider probabilities of occurrences; to predict logical consequences; to weigh evidence or proof; and to use a number of instances to justify a particular conclusion.

As such, proficiency in scientific reasoning can be seen as a key in fulfilling a major objective of American education; the perpetuation of a democratic society comprised of individuals who are capable of governing themselves, free in their ability to employ logical thought in making decisions, and resolving complex problems regarding issues at the personal, local, national, and global levels (Educational Policies Commission, 1961; Welch, 1980).

## Need for the Study

Human society is at a stage where its members direct the course of evolution both of its own species and of the other inhabitants of the earth. Biological principles which were once governed by survival have been altered severely by the effects of human decisions. At this point in human history, many problems set in motion by human decisions without proper foresight appear insoluble. These problems are felt by some (e.g., Rogers, 1961; Block, 1982) to be due in a large measure to individual differences in perceptions of reality. Regardless of cause, however, the future of the entire biosphere relies upon the decision-making capabilities of the members of the human race.

The concern of educators, at any stage within the history of education, has been what to teach and how to teach it. With technology presently advancing at an incredible pace, obsolescence becomes a real threat to the future of society. An over-emphasis in education on content related to the immediate concerns of today's society may result in a population of adult individuals ill-prepared to solve the problems of tomorrow. How best to meet the needs of society and its individuals becomes a problem for those directly involved in determining the course of public education. There can be little doubt that a key to the preparation of a functional public lies in a continued emphasis on the development of problem-solving skills and higher level thinking abilities (Educational Policies Commission, 1961). Facts become relevant in the context of their usefulness. How to acquire needed information quickly and apply it to everyday problems appears to lead a society to the flexibility it requires to keep abreast of change (Harms and Yager, 1980). Carl Rogers (in Taba, 1962) insists that the creation of a society of objective, rational individuals who are capable of managing stress-producing change assures us that there will be a citizenry of individuals aspiring and confident to solve problems themselves. Thus we assure the foundation of our democratic society, a society which values the right of the individual to be the best person he or she can possibly become (Educational Policies Commission, 1961). The production of fully functional human beings capable of making rational decisions regarding their future may, in fact, save the human race from extinction.

Statements regarding the focus for science in the 1980's maintain the need for the adult citizen to be prepared to function in a rapidly changing, technological society. A state-of-the-art report in this regard has recently been prepared by persons working on Project Synthesis (Harms and Yager, 1980). This document suggests ways to diagnose needs and implement curricula to address this thrust in science education. This document reinforces a long-standing commitment of science educators to prepare the public to be scientifically literate.

At one time, inquiry curricula were developed as an instructional strategy to promote scientific literacy in the elementary and secondary school science classroom. Inquiry curricula such as *Elementary School Sciences Program*, *Science--A Process Approach*, *Elementary Science Study*, *Individualized Science*, *Introductory Physical Science*, *Harvard Project Physics*, and *PSSC Physics* were implemented as the means to integrate science concepts into inquiry-based strategies for learning. Inquiry is considered by the science education community to be a general process by which human beings seek information or understanding. Broadly conceived, inquiry is a way of thought based upon rationality, including strategies of problem solving, uses of evidence, logical and analytical reasoning, clarification of values, and decision making (after Welch, 1980). Welch points out, however, that "for many years, science education has advocated the development of inquiry skills as an important outcome of science education, ... and for an equal number of years science educators have met with frustration and disappointment.... In spite of new curricula, better trained teachers, and improved facilities and equipment, the optimistic expectations for students to become inquirers have seldom been fulfilled" (Welch, 1980, p. 53).

Welch proposes that the reason for this lack of fulfillment incorporates two factors: (1) the diversities in human characteristics that affect inquiry-related behaviors have not been taken into account; and (2) the contextual realities of the nation's diverse schools and communities have been disregarded. The view is then presented that not all students should be expected to attain competence in all inquiry outcomes, when such an expectation runs counter to what is known about students abilities and interests and ignores the influence of the school and community environment. A final statement is made by Welch that every student outcome with respect to inquiry in science education should be in agreement with individual differences, personal goals, and environmental conditions (Welch, 1980).

The paucity of significant outcomes in research regarding inquiry curriculum (see Gabel, 1979, for a review) may be due in large part to the individual differences in children that were not considered in the design of experimental studies testing the outcomes for students exposed to inquiry curricula.

The broad purpose of research in this area is to reach an understanding of the external and internal factors involved in life experiences of adolescents which contribute to the development of their abilities in scientific reasoning. If factors or relationships among factors can be identified which appear to influence this ability, then recommendations can be made concerning the scope and sequence of curriculum, what to include as adequate and appropriate scientific knowledge, how much emphasis to place on inquiry in the format of science instruction, how best to prepare those individuals aspiring to science-related professions, and which instructional strategies promote and assure our society of a scientifically literate public.

Several of the variables chosen for inclusion in the present research are ones identified as "individual differences" and which, in an aptitude-treatment-interaction sense, have implications for accommodating the individual differences observed in children in order to effectively provide experiences that enhance the development of scientific reasoning abilities. Research studies have indicated success in learning by accommodating differences in internal and external locus of control, explained in more detail in Chapter Five (see Phares, 1976, for a review); and by the accommodation of differences in field-dependent and field-independent children (e.g., by matching or mismatching teacher traits, as explained by Witkin, Moore, Goodenough, and Cox, 1977). If support is found that the experience variable is indeed key in the development of field independence and scientific reasoning, for example, then direction is provided for the incorporation into the curriculum of experiences in concrete manipulation and mental reformulation which enhance and/or promote field independence and scientific reasoning. If evidence is found for the hypothesized relationships of gender with experience, field dependence-independence, and locus of control, support is acquired for the implementation of suggestions by Fennema and Sherman (1977) and Kahle (1983) regarding the provision of appropriate role models and adequate counseling for adolescent girls in course selection and career decisions. Support for a relationship between scientific reasoning and IQ would lead to expectations from classroom teachers concerning students of varying abilities and their expected performance in reasoning. Regarding the rigidity/flexibility construct, if a strong relationship is found between this variable and scientific reasoning, assumed difficulties in reasoning may be expected beforehand and attempts made to enable children to deal with these difficulties and perhaps change rigid patterns of thought.

## Purpose of the Research

The present research proposes to make both theoretical and practical contributions to the fields of science education and educational psychology by (1) postulating a model for the relationship of relevant variables in predicting ability in scientific reasoning; (2) lending support to the suggestion that certain variables of individual differences (e.g., cognitive style, personality) are linked to particular cognitive abilities of scientific reasoning; and (3) providing a theoretical framework for further research studies which examine the effects of interventions, such as inquiry, on the development of scientific reasoning in individuals possessing particular aptitudes and/or individual differences.

## Problem Statement

The problem addressed in the present research is to formulate and test a model for scientific reasoning ability that will identify predictors of scientific reasoning ability in adolescents and describe the effects of intervening variables on the dependent variable, scientific reasoning; and assess the effects of age on the predictive strength of particular variables with scientific reasoning ability.

## Research Hypotheses

The following research hypotheses are pursued in the present research:

### Hypothesis I

There will be significant ($p < 0.05$) correlations between the following pairs of variables:

I-a. Level of experience and field independence (positive correlation);

I-b. Level of experience and level of scientific reasoning (positive correlation);

I-c. Internal locus of control and field independence (positive correlation);

I-d. Internal locus of control and level of scientific reasoning (positive correlation);

I-e. Age level and level of experience (positive correlation);

I-f. Age level and level of flexibility (positive correlation);

I-g. Age level and level of scientific reasoning (positive correlation);

I-h. Field independence and level of scientific reasoning (positive correlation);

I-i. Flexibility and field independence (positive correlation);

I-j. Flexibility and level of scientific reasoning (positivecorrelation);

I-k. IQ and scientific reasoning (positive correlation);

I-l. Being female and internal locus of control (negative correlation);

I-m. Being male and level of experience (positive correlation);

I-n. Being male and field independence (positive correlation).

## Hypothesis II

Group effects, as based upon age, are hypothesized so that there will be a significant difference in the amount of explained variance between the following pairs of variables in the younger and older adolescent populations:

II-a. IQ and scientific reasoning, with IQ sharing a higher amount of variance with scientific reasoning in the younger population;

II-b. Field independence and scientific reasoning, with field independence sharing a higher amount of variance with scientific reasoning in the older population;

II-c. Internal locus of control and scientific reasoning, with internal locus of control sharing a higher amount of variance with scientific reasoning in the younger population;

II-d. Experience and scientific reasoning, with experience sharing a higher amount of variance with scientific reasoning in the older population.

Hypothesis III

A causal model can be developed for scientific reasoning which involves the variables of experience, locus of control, age, field dependence-independence, flexibility/rigidity, IQ, and gender, where significant path coefficients will confirm each relationship as indicated by the path diagram in Figure 1.1.

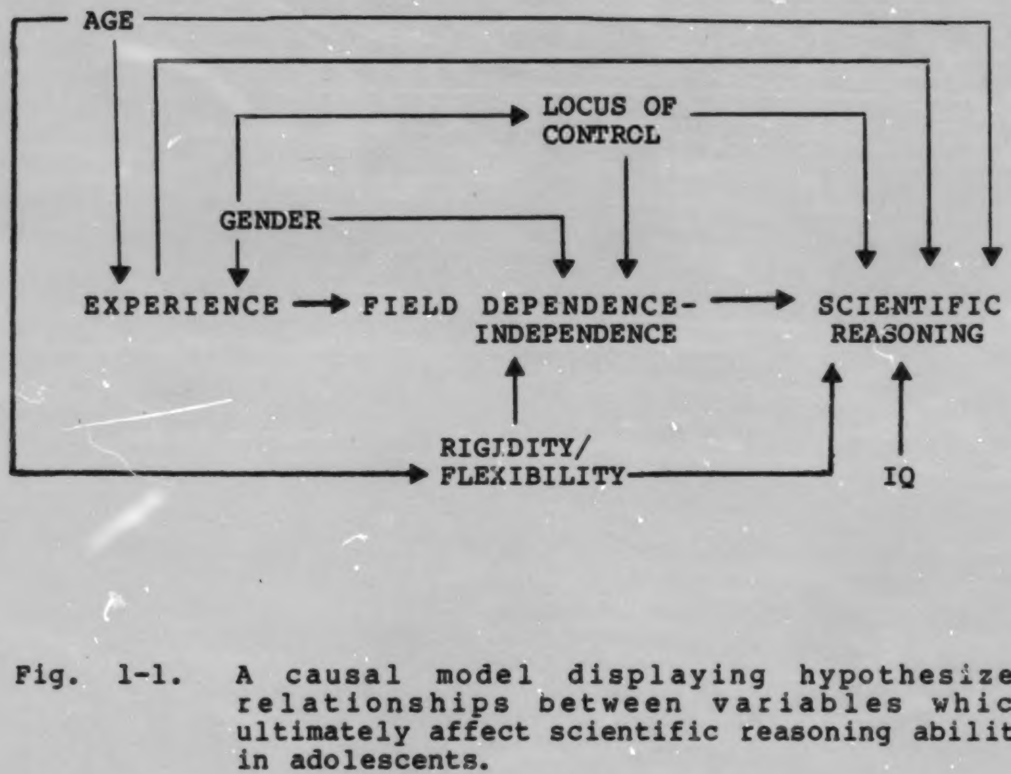

AGE
LOCUS OF CONTROL
GENDER
EXPERIENCE
FIELD DEPENDENCE-INDEPENDENCE
SCIENTIFIC REASONING
RIGIDITY/FLEXIBILITY
IQ

Fig. 1-1. A causal model displaying hypothesized relationships between variables which ultimately affect scientific reasoning ability in adolescents.

## Rationale

### Rationality and Scientific Reasoning

Rationality develops as a normal consequence of unrestricted human experiencing (Bronowski, 1951; Mooney, 1980; Piaget, 1973) resulting in self-actualizing individuals (Maslow, 1962) capable of continued open interaction with the environmental situations encountered in their lives. Thus they continue to grow and exhibit the characteristics of individuals who can, as the situations arise, step out of "safety" (Maslow, 1962, p. 45) in order to experience and logically act on situations which may be threatening or dissonant to what they have already known from their previous experience. Full-functioning individuals are able to employ a number of higher-level logical thought operations included within the term "scientific reasoning" (i.e., proportional reasoning, combinatorial reasoning, controlling variables, an understanding of probability, and syllogistic reasoning; Bronowski, 1951; Cohen, 1953; Inhelder and Piaget, 1958; Piaget, 1972).

### Factors Affecting Scientific Reasoning

A framework for the selection of major variables predicting scientific reasoning was developed from Jean Piaget's theory of genetic epistemology (see Lawson and Renner, 1975, for a concise review). Factors affecting cognitive development identified by Piaget (1964, 1972, 1973) are experience, social transmission, maturity, aptitude, and equilibration. Also, the factors of IQ and gender were chosen because of the extensive research in the area of cognitive development which supports these two variables as strong predictors of cognitive level.

## Assumptions of This Study

### Social Transmission and Locus of Control

A review of Julian Rotter's social learning theory persuaded the author that the construct of locus of control could be used to measure the social transmission factor described by Piaget as being important in cognitive development. Cohen (1953) suggests that "man's ability to question that which he has from childhood been taught or accustomed to accept is very limited indeed unless it is socially cultivated or trained" (p. 84) in discussing variables which affect scientific reasoning abilities.

Lefcourt (1982) has written a recent review of research concerning the locus of control construct. The following is a description of Rotter's research in learning, which indicates implication for the present study:

> Rotter explores the manner in which the internal cognitive processes interact. The child is described as not assimilating new learnings if the action-outcome sequences are perceived as being noncontingent. That is, he will not learn from his experiences unless he believes that these experiences are lawfully related to his own actions. .... It is evident, then that the

> readiness to perceive contingency between one's actions and outcomes is an essential element in understanding how man comes to terms with his daily experience. (Lefcourt, 1982, p. 36)

Data from Crandall cited in Lefcourt (1982) which were comprised of locus of control measures collected during young adulthood, home observations of maternal behavior during the first ten years, and interviews with subjects during early adolescence led Lefcourt to make several suggestions regarding individuals exhibiting a particular locus of control. Adopted in the present study is Lefcourt's suggestion that individuals with an internal locus have more active intercourse with their social environment so that there is more opportunity for them to observe the effect of their own behavior, the contingency between their own actions and ensuing events, unmediated by the intervention of significant others into their lives. It is assumed that a measure of this construct will indicate the degree of readiness possessed by an individual to engage in, direct, pursue, or initiate social interventions when resolving cognitive conflicts brought about by discrepant experience.

## Equilibration and Rigidity-Flexibility

Although no attempts have been made to operationalize the elusive equilibrium factor of Piaget, this factor has recently been redefined along psychological rather than physiological lines (Block, 1982). Block chose to redefine

Piaget's cognitive disequilibrium from a psychological model, suggesting that mediating variables in the form of personality or cognitive style may affect the manner in which an individual approaches cognitive disequilibrium. Block speculated that some persons, in reacting to new experiences which fail to conform to the expectations generated from existing schemas, are able to (and even insist on doing) encompass the new information in ways that require little or no modification of previously established premises. Other persons encountering discrepant experiences have a greater readiness (and even preference) for leaving schemas that do not mesh readily with the new information and move on to the formulation of new and sufficient meaning-making structures. Individual differences in reacting cognitively to discrepant experiences may thus have the effects of enhancing, retarding, or blocking the development of logical mental structures. It was from this suggestion by Block and the theoretical frameworks of Frenkel-Brunswik (1949) and Rokeach (1960) that the personality construct of flexibility-rigidity was chosen as a probable construct mediating organism-environment interactions and thus which might affect outcomes in scientific reasoning ability.

After the consideration of several possibilities for measuring the rigidity/flexibility construct, the Breskin Rigidity Test (BRT) was chosen. The BRT is a non-verbal test which was developed on the basis of a perceptual rather than a conceptual frame of reference to indicate the rigid individual who requires a greater degree of structure in his environment than the more flexible individual (Breskin, 1968). Breskin postulated that a requirement for structure would be manifested in the Gestaltist law of Praegnanz, which states that a more rigid person, given the opportunity to express a preference between pairs of figures differing only in "goodness of fit," will tend to select the "better" fit. Breskin designed the test so that a rigidity score was taken to be the total number of Praegnanz items selected.

In individuals who exhibit high degrees of rigidity, scientific reasoning abilities should occur less frequently, perhaps due to the alterations occurring within the individual, as suggested by Block (1982). Block explained that these alterations may cause the individual to equilibrate the perceived experience unrealistically. A speculation on the modes of equilibration for this particular personality variable is that individuals exhibiting perceptual rigidity would have rigid perceptions of what they encounter, demanding premature closure on ambiguous or "open" events. Equilibration may therefore be dictated by preference for unambiguous experience. In situations which call for tolerance of ambiguity and reflection, cognitive dissonance may not occur because the individual prefers to act upon experience which is congruent to his mode of perception (Block, 1982; Frenkel-Brunswick, 1949; Rokeach, 1960).

### Aptitude and Field Dependence-Independence

The definition of the field dependence-field independence construct led several authors (e.g., Lawson and Wollman, 1977; Vernon, 1972, Weisz, O'Neill, and O'Neill, 1975) to explore this measure of cognitive style and its relationship to higher thinking operations. Relationships between field independence and formal thought were reported in a number of studies (e.g., Nagy and Griffiths, 1982; Levine and Linn, 1977; Linn and Swiney, 1981). This author has chosen to adopt field independence as an aptitude for scientific reasoning, the definition for "aptitude" being "any characteristic of a person that forcasts his probability of success under a given treatment" (Cronbach and Snow, 1977, p. 6). The rationale presented by Cronbach and Snow for a broadly based definition is accepted in the present study as being consistent with Piaget's (1972) description and the research cited above.

## Definition of Key Terms

The following terms are used in this study:

*Scientific reasoning ability*. -- Mental functioning characterized by the ability to use the hypothetico-deductive strategies of propositional logic, proportional reasoning, combinatorial reasoning, controlling variables, and probabilistic reasoning. Individuals who exhibit the inability to use these strategies, or an inconsistency in their use, demonstrate low abilities in scientific reasoning. Conversely, individuals who demonstrate a consistent use of these strategies are classified as having high ability in scientific reasoning.

Experience. -- Cognitive and recreational activities common to adolescents which have been evaluated by educators as predicting ability to perform scientific reasoning tasks.

Social Transmission (Locus of control). -- The perceived control of an individual in terms of his or her expectancies for reinforcement.

External control. -- The generalized expectancy referring to the perception by the individual that positive or negative events are unrelated to one's own behavior and therefore beyond personal control.

Internal control. -- The generalized expectancy that the individual's perception of events, where positive or negative, as being a consequence of one's own actions and therefore potentially under personal control.

Maturation. -- Age in years and months.

Aptitude (Field Dependence-Independence). -- A hypothetical construct developed to explain the process of mediation between stimuli and responses; the characteristic tendency demonstrated by individuals to conceptually organize the environment, with an emphasis on structure rather than on the content of thought.

Field dependence. -- The cognitive style tendency of an individual to adhere to the organization of the prevailing field.

Field independence. -- The cognitive style tendency to perceive part of a field as discrete from the surrounding field as a whole rather than embedded in the field, likely to overcome the organization of the field or to restructure it symbolically to be used in a different context.

Equilibration.-- A construct centering on the personality variable of rigidity-flexibility that refer to the degree of openness (flexibility) or preference for closure (rigidity) of individuals experiencing their environment.

Open preference. -- A tendency towards openness and tolerance of lack of structure in selecting visual abstract characters which violate the laws of Praegnanz.

Closed preference. -- A tendency towards closure and requirement of structure in selecting visual abstract characters which do not violate the laws of Praegnanz and demonstrate "goodness of fit."

## Variables Considered in This Study

Table 1-1 lists the variables considered for sample populations of adolescents at two age levels. A brief discussion of the variables and their corresponding instruments follows:

### Scientific Reasoning Ability

Thirteen items from the Test of Formal Operations (Lawson, 1978) and two questions developed by the author were used to assess level of scientific reasoning ability. (Appendix E is a copy of the Scientific Reasoning Test.)

### Experiential Variable

Self-report data were collected on the Cognitive and Recreational Activity Scale (CRAS) developed by the author to indicate the depth and variability of logico-mathematical experience and manipulative experience of the individuals participating in this study. (A copy of this instrument is displayed as Appendix B.)

### Social Transmission Variable

A *locus of control* measurement was taken to determine the extent to which an individual perceives his own control over experiences within the environment. The Crandall Intellectual Achievement Responsibility Questionnaire (Crandall, Katkovsky, and Preston, 1962) was used. (A copy of this instrument is displayed as Appendix D.)

## TABLE 1-1

## VARIABLES EXAMINED IN THE RESEARCH WITH THEIR CORRESPONDING CONSTRUCTS AND INSTRUMENTS

| VARIABLE | CONSTRUCT | INSTRUMENT |
|---|---|---|
| Experiential Variable* | | Cognitive and Recreational Activity Scale (CRAS) |
| Social Transmission* | Locus of Control | Intellectual Achievement Responsibility Questionnaire (IAR) |
| Maturation* | | Age |
| Aptitude* | Field Dependence-Independence Independence | Concealed Figures Test (CFT) |
| Equilibration* | Rigidity/ Flexibility | Breskin's Rigidity Test (BRT) |
| IQ | Ability to learn | Short Form Test of Academic Aptitude (SFTAA) |
| Gender | | |
| Scientific Reasoning Ability | | Scientific Reasoning Test (SRT) |

* Those variables marked with asterisks are ones which were identified by Piaget as affecting the development of formal operational thought.

### Maturational Variable

Age in years and months was self-reported on a data sheet.

### Aptitude Variable

The Concealed Figures Test, Form A (Thurstone and Jeffrey, 1956), was used to measure the construct of field dependence-independence.

### Equilibration Variable

Breskin's Rigidity Test (Breskin, 1968), a non-verbal test of rigidity, was used to measure perceptual rigidity, the extent to which an individual prefers closure in perceiving experience. (Appendix C is a copy of this test.)

### IQ and Gender

IQ data were gathered from students' permanent school records. The most recent total IQ scores on the Short Form Test of Academic Aptitude (SFTAA) was used. Gender was self-reported on a background sheet.

## Limitations

The subjects under study were secondary school students attending predominantly white, upper middle class schools in a suburb of Columbus, Ohio. They consisted of children between the ages of 11 and 17 who, with the consent of their parents, agreed to participate in the study.

Generalizations drawn from the data collected from the participants of this study are limited to sample populations of students with similar socio-economic backgrounds. As well, this study is limited to measurements used in the study.

## Summary Statement of Chapter One

Constructed within this chapter is a framework for the present study which aimed to examine the interactive effects of experience, social transmission (locus of control), maturity, aptitude (field dependence-independence), equilibration (personality: rigidity/ flexibility), IQ, and gender in adolescents exhibiting differing abilities in scientific reasoning. This framework was based upon an interactive model of man (Mooney, 1980), the premise that motivation for growth is based upon a principle of "full functioning" and self-actualization (Maslow, 1962; Rogers, 1961), and a theory for cognitive development that higher level thinking abilities (such as those employed in scientific reasoning) develop with maturity, continued experiences, social transmission, and aptitude through equilibration, i.e., the mental reformulation of concrete experience (Piaget, 1973).

A broad purpose of the present research was to show that the entirety of man's experience, within and without himself, affects the development of his powers of rationality. And in order to promote scientific literacy in our public, we must not only acknowledge the importance of the external elements of the environment and the genetic characteristics of individuals interacting within that environment, but acknowledge as well the internal elements of the individual himself which either enhance or discourage the development of his rational skills.

## CHAPTER TWO

## REVIEW OF THE LITERATURE

### Section I. Introduction

This chapter presents a review of the literature which supports the proposed model regarding variables affecting the development of scientific reasoning abilities in adolescents. Literature chosen for review includes theoretical considerations and empirical studies which aided in the identification of potential determinants of scientific reasoning in the development of the model shown in Figure 1.1. Briefly, the chapter is organized into four sections. Section I, the Introduction, provides a historical overview of the development of rational thought, delves into the philosophical considerations regarding some modern conceptualizations of scientific reasoning, and establishes a relationship of scientific reasoning to Piagetian theory in terms of the development of formal operational thought. Section II, which comprises a major portion of the chapter, reviews one-by-one the variables chosen as those potentially affecting the development of scientific reasoning abilities. Theoretical considerations regarding the variables are presented first, and a rationale developed if necessary for the choice of a particular construct to represent that variable (e.g., field dependence-independence for the aptitude variable). Empirical results supporting the proposed relationships of that variable with others in the model are then discussed. Concerning these proposed relationships, a format has been adopted to facilitate discussion and avoid overlap: the variable is discussed in its role as an independent variable only, affecting the dependent variable(s) as indicated by the arrows in Figure 1-1. Finally, the instrument chosen to measure the particular variable is discussed. This discussion may precede or follow the discussion of empirical research; where the particular instrument has been used in empirical research which has considered variables significant to the present research, the discussion regarding the instrument precedes the discussion on empirical studies supporting the relationships proposed. Section III reviews the results of a pilot study run prior to the present research, and Section IV presents a brief summary of path analysis as the statistical method chosen to test the causal model proposed in this study.

## Rational Thought

Within the repertoire of man's adaptive activities which come under the broad category of "thinking," rational thought has held an eminent position since the time of the early Greeks. The Greeks defined man as the "rational animal," and were the first to identify rational consciousness as a separate psychic function -- differentiated from man's feelings and intuition. Reason was perceived by Plato as the divine part of man, separated from the animal within him. Plato's theory of rationalism promised man salvation from the things he had feared most from the earliest days, from death and from time, by opening up the realm of eternal truth, or Ideas, Universals, which become through abstraction more "really real" than individual people or particular objects in the universe (Barrett, 1962). As such, rationality admitted causality, order, and predictability into an otherwise chaotic world.

The adaptive significance of rationality is seen when one adopts the model of man as an active, open, curious, growing biological system (Dewey, 1916; Mooney, 1980; Piaget, 1972). With such a model, rationality frees man to experience fully the realities of himself, his actions, and his ideas in a constantly changing, very complex environment. Ordered, systematic, abstract thought enables man to experience, reflect upon, and generalize beyond the specific events in his environment, to expand his frame of reference and thus allow for a stable, consistent way of perceiving the world and himself within it.

Within a psychological framework, rationality provides a mechanism for adjustment to changes brought about by normal growth and experience Block, 1982; Mooney, 1980; Piaget, 1972). Rational thought in this context is viewed as the regulative activity employed to correlate all factors of experience by fully functioning human beings who embrace life as healthy individuals, integrated emotionally, physically, and intellectually, and striving towards becoming the best human beings they can possibly become (Maslow, 1962; Rogers, 1961).

Motivation towards rationality can be viewed psychologically as an adaptive force of the "rational animal" which allows for flexibility in the environment: it enhances survival of the particular individual and of the human species as well (Block, 1982; Bronowski, 1951; Mooney, 1980; Piaget, 1972; Wilson, 1978). As such, rational thought enables man to perceive realistically and act appropriately upon what he experiences.

The adaptive organ of the human organism is his brain, which allows him to determine the "fit" of a new experience relative to prior experiences. If a new experience is one similar to others he has experienced, the brain passively takes in or assimilates the experience (Piaget in Rychlak, 1981; Rogers, 1961). If, on the other hand, the experience is discrepant to those which an individual already knows from his repertoire of prior experiences, a state of cognitive conflict or tension arises, which requires resolution. Reduction in cognitive conflict ensues by active accommodation, a mental process which entails the alteration of pre-existing cognitive structures in the brain or the production of new cognitive structures that relate the discrepant experience to prior experience. Within the context of the philosophy of science, individuals such as Jacob Bronowski and Morris Cohen have also claimed that rational thought is adaptive and characteristically human--that which enables the active restructuring of human experience and therefore the prediction of future events, the "characteristic activity of human life" (Bronowski, 1951, pp. 103-104). Bronowski in The Common Sense of Science developed the point that the present in man's experiencing can be viewed as providing a set of signals which are made continuously to yield a meaning from which the future is anticipated. Further, he explained science as a process of prediction which is conscious and rational (as opposed to intuitive), and that rational prediction is a major contributor to the success of the human species in adaptation to the environment.

## Scientific Reasoning

Scientific activity, as Bronowski described it, consists of not only the rational thinking process but also of empirical fact-finding as well. Bronowski traced the origin of modern science in Descartes' development of logical thinking and in Bacon's methods of experimentation, both products of the early seventeenth century. With Isaac Newton's formulation of the principle of gravity, which

Bronowski noted as a "remarkable marriage of the logical and empirical method" (pp. 31-32), the first fusion of the two methods of science occurred. Bronowski's description of how these two methodologies interact in scientific activity is excerpted below:

> In order to act in a scientific manner, in order to act in a human manner at all, two things are necessary: fact and thought. Science does not consist only of finding the facts; nor is it enough to only think, however rationally. The processes of science are characteristic of human action in that they move by the union of empirical fact and rational thought, in a way which cannot be disentangled. This is in science, as in all our lives, a continuous to and fro of factual discovery, then of thought about the implications of what we have discovered, and so back to the facts for testing and discovery--a step by step of experiment and theory, left, right, left, right, forever. (pp. 32-33)

The actual constitution of the logical methodology of science was thoroughly examined in Morris Cohen's (1953) essay on the meaning of scientific method, Reason and Nature. Cohen's viewpoint concurs with Bronowski: that scientific method fuses reason and empiricism. It differs, however, in that Cohen demands more precision: "To say that science is organized or classified common sense, is to be satisfied with very vague words" (p. 79).

It is by tracing Cohen's precise description of the "ideal of science" within the chapter entitled "Reason and Scientific Method" that descriptions and explanations of the actual mental operations involved in scientific reasoning are elucidated. Cohen's description of scientific reasoning parallels the description by Lawson (1982) of "advanced reasoning." These references were used to formulate a description of "scientific reasoning ability," for the present research as follows: Scientific reasoning involves thought processes which are re hypothetico-deductive; they are based upon propositional logic and employ the method of logical proof; and they require the use of particular thinking strategies or schemata such as proportional reasoning, combinatorial reasoning, probabilistic reasoning, and the separation and control of variables.

## The Relationship of Scientific Reasoning to the Development of Formal Operational Thought

A theory for human cognitive development based upon the acquisition of logical operations was formulated by Jean Piaget, a child psychologist who had a strong background in formal biological science. Briefly, Piaget's theory of "genetic epistemology" provided for the development of logical thought processes through a series of levels and/or stages more or less linked to the child's chronological age. Children progress through the stages by the process of equilibration, which assures that new thoughts or discoveries balance with other mental structures the child has already acquired. Pre-existing mental structures are altered by encounters with discrepant experience, producing new structures. It is by the process of equilibration that learning, as well as growth in thinking, occurs. Piaget theorized that individuals ultimately reach formal operational thought sometime during the period of adolescence, at which time an individual would demonstrate the consistent use of a number of higher-level mental schemata. Phillips (1975) interpreted Piaget's viewpoints concerning "the real versus the possible," in terms of the transition in thinking that occurs during the period of adolescence, which Piaget would say occurs during the transition in thinking from concrete operations to formal operations:

> As he grows older and gains more experience, the child's construction of reality becomes more precise and extended, and that makes him aware of gaps in his understanding that had been asked by the vagueness of his previous constructions. He fills those gaps with hypotheses, and he is able to formulate--and often even to test--hypotheses without actually manipulating concrete objects. More accurately, he develops a new theoretical synthesis in which "certain relations are necessary," so that particular propositions can be checked, not only against the data of his senses (and against the data-bound mental operations of the the previous period; i.e., the concrete operational) but also against this new structure of possibilities. In fact, he begins by considering possibilities. (Phillips, 1975, pp. 129-130)

An examination of research which addresses the identification of the particular mental schemata operating in hypothetico-deductive thought revealed considerable consistency (e.g., Bybee and Sund, 1982; Inhelder and Piaget, 1958; Lawson, 1978, 1982; Padilla, Okey and Dillashaw, 1983). The individual schemata of combinatorial, proportional, and probabilistic reasoning, and the isolation and control of variables were grouped in some instances to

$p \subset q$ and the events $\bar{p} \cdot q + p \cdot \bar{q}$ are not expected to occur. He also speculated that the basic pattern of hypothesis generation and testing was the same in each of the schemata listed above.

Using the theoretical viewpoint of Lawson, who developed the test from which most of the items for the measurement of scientific reasoning were chosen for the present study, this researcher established a link between the hypothetico-deductive, "advanced causal reasoning schemata" of Lawson (1982), which "function in different parts (or at different times) during the hypothesis generation and testing process" (Lawson, 1982, p. 757), and the hypothetico-deductive scientific methodology of Bronowski (1951) and Cohen (1953). Further, empirical support for this link was found in the preliminary research by Padilla et al. (1983). A significant ($p > 0.0001$, with a corrected coefficient of 0.73) relationship was found between total test scores of integrated scientific process skills (TIPS) and logical thinking (TOLT) abilities. Included within Padilla's list of integrated processes were the formulation of hypotheses, designing experiments, and making generalizations after collection of data. The schemata tested in the Test of Logical Thinking (Tobin and Capie, 1981) included proportional thought, controlling variables, probabilistic logic, correlational logic, and combinatorial logic.

represent an indication of the "stage of formal operations," as originally theorized by Inhelder and Piaget (1958) and supported by Lawson's earlier work (Lawson, 1978; Lawson and Renner, 1975) and Bybee and Sund (1982), who refer to the "formal operational level." The same schemata may be used as examples of "logical thinking" (Tobin and Capie, 1981), "cognitive tendency" (Farnsworth, 1981), "advanced reasoning" (Lawson, 1982), or "formal thinking abilities" (Padilla et al., 1983).

The controversy regarding whether possession of the schemata indeed does indicate the attainment of a formal operational stage was addressed recently by Lawson (1982). Lawson summarized research results as inconclusive regarding the notion of "stage," and showed a shift in his own theoretical viewpoint by grouping the schemata within the term "advanced reasoning." A model was presented by Lawson "in which hypothesis generation and testing are viewed as central processes in intellectual development" (p. 758). A number of schemata were considered by Lawson as examples of advanced reasoning, which he related to the overall process of generating and testing hypotheses: generating expectations, controlling variables, combinatorial reasoning, probabilistic/correlational reasoning, and proportional reasoning. Lawson theorized that these aspects of advanced reasoning involve a 2 x 2 mental matrix in which the events $p . q + \bar{p} . \bar{q}$ are expected to occur assuming

Several of the "scientific reasoning" items in the present study were chosen from Lawson's Test of Formal Operations (Lawson, 1978), which was designed to test for the ability to perform the mental operations of controlling variables, combinatorial reasoning, probabilistic reasoning, and proportional reasoning. Lawson's proposition that the test could also predict operational level of cognitive development was not pursued in the present research. It does appear appropriate, however, to use the Lawson items measuring abilities in using hypothetico-deductive schemata "which facilitate the processes of generating and testing hypotheses" (Lawson, 1982, p. 757) to measure the same schemata associated with "scientific reasoning" in the present study.

# Section II. Factors Affecting the Development of Scientific Reasoning Abilities

## Introduction

### Experience, Social Transmission, and Maturation--The Original Piagetian Variables

Three main factors, experience, social transmission, and maturation, were isolated by Piaget as those affecting the process of equilibration. It is obvious that without *experience* within the environment no contradictions of present mental structures arise, and thus no learning occurs. Piaget described two basic kinds of experience - physical and logico-mathematical. Physical experience is actual physical action on objects in the world, which leads to the development of mental structures about objects. At some point, the child begins to recognize more in his interaction with the world than just objects. He sees that his actions with objects produce order in themselves (Lawson and Renner, 1975). A product of this realization is the development of a logico-mathematical mental structure that can be utilized in many situations which enables the learner to operate consistently and logically within his environment.

Piaget's second factor, *social transmission*, is also necessary for mental structure building. Lawson and Renner (1975) gave the example of a very young child who operates from an egocentric frame of reference. The child is not able to see things objectively because he always relates them to himself. This sort of thinker cannot objectively view and/or evaluate anything. "In order for the learner to be shaken from his egocentric views, he must experience the viewpoints and thoughts of others" (Lawson and Renner, 1975, p. 339). In other words, interaction with others, in the forms of conflict, debate, sharing data, and actively attempting to delineate other viewpoints, allows an opportunity for equilibration to occur.

The third factor, maturation, reflects the child's mental capacity for processing information, which increases more or less linearly with age (Lawson and Renner, 1975). Case (1979) explains that a child of 5-6 years of age can recall two digits and say them backwards; this ability to recall and transpose digits is increased to three by the age of 7-8; and by the age of 15-16, it has reached a maximum of about seven. This constraint on a child's ability to store and mentally manipulate information limits the child's ability to comprehend complex conceptualizations. It has been speculated by Piaget that the growth of this mental capacity is dependent on the growth of the central nervous system (Piaget, 1973).

Piagetian theory, then, provided that the alteration of mental structures was dependent upon these three factors linked through the process of equilibration. Sometime within the period of adolescence, Piaget theorized that an individual would possess a set of constant mental structures which resulted from the process of equilibration and which could be used to classify the form of his thought. People exhibiting a set of mental structures which included various forms of higher-level thinking operations were classified as being formal operational in their thinking. The present study, as explained in the previous section, assumed that individuals possessing skills in scientific reasoning possess and consistently use schemata which have been labeled by Piagetians as formal operational.

## Aptitude and Equilibration--Factors of Importance in Adolescence

Original research by Inhelder and Piaget (1958) concluded that all normal individuals reach a stability in the use of formal operations between the ages of 11 and 15. However, more recent research (e.g., Elkind, 1962; Lawson and Renner, 1974; McKinnon and Renner, 1971; Schwebel, 1975; Towler and Wheatley, 1971; Walker, Mertens and Hendrix, 1979) contradicted Piaget's conclusions that all adults develop formal operational thought. In these examples of research with college students and adults, it was shown that some, but by no means all, late adolescents and adults were formal operational thinkers.

Piaget (1972) addressed the matter of growing discrepancies with his original research reports and suggested that the three factors identified above (i.e., experience, social transmission, and maturation) may have been inadequate in subjects of studies in which the discrepancies were found. As well, Piaget also introduced the notion that there may be a possibility of diversification of aptitudes with age. He suggested that cognitive differences in the representation of space, for instance, may act to distinguish mathematicians who think more abstractly (i.e., the "algebrists") from those who think more concretely (i.e., the "geometricians"). He also questioned the generalizability of the testing situation under which he determined developmental level and introduced the notion that perhaps a person, due to experience, acquires formal reasoning only in his own area of specialty, even though his general education is limited.

Although not specifically addressed in this paper, a fourth factor (beyond maturity, social transmission, experience, and aptitude), is central to Piaget's theory of cognitive development, particularly at adolescence: equilibration. Piaget (quoted in Rychlak, 1981) described equilibration in ambiguous terms, as an "ineluctable rhythm," which balances the organism's assimilation and accommodation of his environment. Although more specific descriptions of the process of equilibration might aid in operationalizing this determinant of cognitive development, it has been noted by researchers such as Bybee and Sund in the field of Piagetian theory that lack of knowledge about this factor represents a "serious omission from the major work of Piaget" (Bybee and Sund, 1982). The following description, from Piaget himself (Piaget, 1972), although ambiguous, suggested to the present researcher that Piaget was hinting at qualities of individuals which could be operationalized in terms of cognitive style or personality constructs, individual differences which may affect the acqusition of formal reasoning abilities.

> I take the word equilibrium not in a static sense but in that of a progressive equilibration, the equilibrium being the compensation by reaction of the child to the outer disturbances, a compensation which leads to the operatory reversibility at the end of this development. (Piaget, 1972, p. 29)

An introductory statement by Piaget in a later paper acknowledged the complexity of the issue concerning development of formal cognitive structures during adolescence:

> The important changes that take place in adolescence in cognitive function and structure ... show how much this essential phase in ontogenic development concerns all aspects of mental and psychophysiological evolution and not only the more "instinctive," emotional or social aspects to which one often limits the period which separates adolescence from adulthood. (Piaget, 1973, p. 1)

This statement by Piaget allows considerable flexibility for the researcher in the search for variables other than experience, maturation, social transmission, equilibration, and aptitude affecting cognitive function and structure. With this in mind, two other variables, IQ and gender, were included.

## IQ and Gender--Non-Piagetian Variables

Two variables are included within the present study which have not been addressed directly in Piagetian writings as being determinants in cognitive development: IQ and gender. These variables, however, have been examined in a number of research studies dealing with cognitive abilities, providing evidence for either direct or indirect relationships of IQ and/or gender with scientific reasoning ability. The discussion below presents a brief overview of how these variables may interact with scientific reasoning as defined in the present research.

The IQ score is viewed in this research as an operational, observable, and measurable representation of intelligence. To the extent that an IQ test is accepted as a valid measure of intelligence, the educational value of such a test has been in its ability to predict an "ability to learn." Opinions have varied, however, regarding definitions of intelligence, ability to learn, and how the IQ score relates to these conceptualizations. Such concerns are discussed in detail later in Section II of this chapter. It is the opinion of this writer that these differences in theoretical frameworks have affected the interpretation of studies examining the relationship between IQ and Piagetian operational levels. (See DeVries, 1974; Keating, 1975; Weisz, O'Neill, and O'Neill, 1975). The fact remains, however, that IQ has consistently been a moderate to strong predictor of cognitive abilities. For this reason, IQ was examined as a potential determinant of scientific reasoning ability. It was also anticipated that the relationship between IQ and scientific reasoning ability would have value in offering a baseline in terms of predictive strength, to which other proposed relationships in the present research could be compared.

Recent literature supports the existence of sex-related differences in some areas of cognitive functioning; but gender differences in empirical studies dealing with Piagetian cognitive development are most often not supported. When differences have been reported, differential experience and maturational effects have often been discussed as confounding factors. Because there is a substantial amount of research indicating relationships between gender and other variables included within the present study (e.g., experience, field dependence-independence, and locus of control), the indirect effects of gender through other variables in the ultimate attainment of scientific reasoning ability were hypothesized.

With this introduction to the variables chosen for examination in the present study, the discussion now proceeds to summarize theoretical considerations and empirical research which led the researcher to propose the direct and indirect effects of these variables on the ultimate variable of interest, scientific reasoning ability.

## A. Experience

### Theoretical Considerations

A philosophical viewpoint that experience produces generalizations regarding oneself and one's environment is reflected in the writings of Ross L. Mooney (1979). Mooney's view was that "Each person is a system for organizing experience from his time-space position in the universe," that "Through experience with a number of years, a person can get a clearer perspective of the time-space position from which he composes and speaks; and that as this position clears up, so also does his conception of his environment," and that, "with the meeting of more and more experiences, more and more sorting occurs so that generalizations, or guiding principles, emerge which are characteristic of the way one does his sorting" (Mooney, 1979, p. 1).

That the motivation for experiencing arises from "higher needs of curiosity and exploration," which may be in conflict with a "lower need" of safety is accepted by self-actualizing theorists such as Abraham Maslow and Carl Rogers. Maslow contended that the anxiety-free person can be more bold and more courageous and can explore and theorize for the sake of knowledge itself. He concluded that "it is certainly reasonable to assume that the latter is more likely to approach the truth, the real nature of things" (Maslow, 1962, p. 62).

The relationship between experience and thinking was discussed in Dewey's (1916) Democracy and Education. Dewey explained the nature of experience as including an active and a passive element peculiarly combined: experience is trying (i.e., the active), and it us undergoing (the passive).

> When we experience something we act upon it, we do something with it; then we suffer or undergo the consequences. We do something to the thing and then it does something to us in return: such is the peculiar combination. .... When the change made by action is reflected back into a change made in us, the mere flux is loaded with significance. We learning something. (Dewey, 1916, p. 139)

Dewey further explained that "learning by experience" is like doing an experiment with the world to find out what it is like, that the undergoing becomes instruction--discovery of the connection of things; that experience is essential in the understanding of relationships; and that thinking is the "intellectual endeavor to discover specific connections between something which we do and the consequences which result so that the two become continuous." Dewey conceptualized all thinking as research, a process of inquiry, which included a number of steps, based upon an experience which stimulates the need to institute a connection between what is done and its consequences.

## Experience and Scientific Reasoning

Jean Piaget also stressed the importance of experience in the development of thinking, in particular, in the development of logical thinking or reasoning. Piaget explained that the development of reasoning in the child is based on experience of two kinds: physical experience, which leads to the development of mental structures about objects and logico-mathematical experience, which leads to the development of mental structures which by the time of adolescence enable one to abstract, think about thought, and to reason propositionally (Inhelder and Piaget, 1958). Kamii (1973) explained how the knowledge resulting from physical experience and logico-mathematical experience differ. "Physical knowledge (i.e., that brought about by the action on objects) can be built by discovery, but logico-mathematical knowledge (i.e., that brought about by logico-mathematical experience) cannot. It can be built only by the child's own invention" (p. 208). By acting on objects, a child discovers their properties, but in logico-mathematical knowledge, the child cannot make discoveries from the objects themselves. The logico-mathematical structures have to be invented, or created, by the child's own cognitive activity rather than discovered from the reaction of objects.

Piaget postulated that a deficiency in experience may lead to delay in the acquisition of formal operational schemata. McCrary and Long (1980) reviewed research in the area of experience, which they called "environmental stimulation," and cognitive functioning. These authors reviewed studies which addressed a broad spectrum of experiential variables assumed to affect formal thought acquisition in adults, including culture, socio-economic status, familiarity and credibility, education, institutionalization, and activity and isolation. Regarding the last variable, McCrary and Long quoted Hunt, who said that the greater the variety of situations to which the child must accommodate his "behavioral structures," the more differentiated and mobile these structures become. Conclusions by McCrary and Long, as a result of their review of related literature, were that a number of factors (culture, education, activity, isolation, and training) support the significant positive effect of environmental stimulation upon level of adult cognitive functioning.

Other reviews (Gabel, 1979; Nagy and Griffiths, 1982) addressed only the training effects in the classroom situation on development of formal thinking. Although McCrary and Long reached a firm conclusion that training affects level of cognitive functioning, questionable effects were reported by Gabel. Gabel evaluated a number of studies which examined various types of classroom experience and concluded that generalizations made from most of the studies should be made with caution, due to the research methods employed. The more recent study by Nagy and Griffiths extensively examined studies involving training treatments. As with the Gabel review, Nagy and Griffiths came to no clear conclusions regarding long-range effects with training for acquisition of formal schemata.

On a much broader scale, DeCarlo (1974) concluded that any experience which requires intellectual exercise, whether in the classroom or in recreational pursuits, enhances and/or sustains the intellectual endowment of the individual at whatever the capacity of the individual. In the DeCarlo study, which addressed successful ageing in octogenarians, a Recreative Activity Scale was developed to measure the range of participation and frequency of participation in activities, classifying these activities according to stage in the life span, and behavioral domain. Among DeCarlo's findings were a significant ($p < .01$) and positive relationship between cognitive recreative activities and intellectual performance.

The DeCarlo (1974) study, research by Kamii (1973), and personal discussions with educators who work with adolescents and adults suggested to this investigator that participation in activities which involve active mental reformulations with actions on concrete objects (e.g., sculpture, carpentry, sewing or building from a pattern, fixing things that are broken) or in activities which involve high levels of abstraction void of concrete manipulations (e.g., solving word problems in math, writing poetry, writing stories, doing geometry problems) might enhance the development of higher level mental schemata used in scientific reasoning. Sherman (1967) noted the sex differences involved in such activities: "Boys as a group spend more time in aiming activities and games, model construction, building with blocks and later with other materials. It seems very likely that these activities are involved in the development of spatial skills" (pp. 295-296). (See G. Gender for a more complete discussion of gender differences as a variable affecting experience and field dependence-independence.)

### The Cognitive and Recreational Activity Scale as a Measure of Experience

The Cognitive and Recreational Activity Scale was developed within the course of the present research as a means of determining the extent to which children have engaged in activities, both in and outside of school, which were identified as contributing to the development of scientific reasoning in adolescents. Initially, a list of activities was compiled by this author. The list contained a number of activities identifed by the author on the suggestions of science educators and was compared to a similar list of activities identified as common to gifted adolescents by Renzulli (1977). This list of 26 items was submitted to ten secondary school educators for evaluation as to degree of contribution to scientific reasoning skills. Means of these scores are reported in Appendix A. The final scale, as presented to subjects in the present study, consisted of those items which had a mean value of 2.00 or above. This scale is included as Appendix B.

### Experience and Field Dependence-Independence

Experiences which were identified as affecting the development of scientific reasoning abilities during the development of the Cognitive and Recreational Activity Scale for the present research were very similar to those suggested by a number of authors (e.g., Brinkmann, 1966; Fennema and Sherman, 1977; Kahle, 1983; Sherman, 1967; Tanner and Inhelder, 1958) as enhancing the development of abilities in "spatial visualization," a term which often appears as synonymous with field dependence-independence in these and other references. A discussion regarding the relationship between field dependence-independence and scientific reasoning ability appears later in this section. The objective here is to summarize evidence from a number of sources which have shown that in-school and out-of-school experiences have been identified and researched that indicate a cause-and-effect relationship between certain kinds of experience and field independence.

Sherman (1967) presented an extensive review of several key studies in the section entitled "Differential Practice As a Key to Causation" which indicated a number of useful findings regarding the enhancement of spatial visualization abilities: training in estimation and visualization techniques; programmed learning in geometry and working with materials which provide for tactual-kinesthetic visual feedback; experiences involving more independence and less reliance on the classroom teacher; mechanical drawing as coursework; jobs and hobbies of a mechanical or technical nature which involve spatial work; spare-time activities of tinkering with cars, sports, model building, driving a car, direction-finding, and map reading; aiming activities and games, model construction, building with blocks and other materials. The differential effects due to gender in engaging in many of these activities are obvious, an observation noted by Kahle (1983) in her discussion of women as the "disadvantaged minority" in science education. These effects will be discussed in detail in the section which deals with gender as an independent variable.

## Hypothesized Relationships Concerning Experience as an Independent Variable

From studies chosen for review to explore experience as the independent variable, these relationships were hypothesized for the present study: between experience and field dependence-independence, with more experiences in action upon objects and mental restructuring, as measured by the Cognitive and Recreational Activity Scale, predicting field independence; and between experience and scientific reasoning abilities, with more experience in mental restructuring and spatial visualization predicting higher scores in scientific reasoning. Figure 2.1 highlights these relationships.

## B. Locus of Control

### Theoretical Considerations

Piaget (1972) asserted that the difference in speed of the acquisition of formal thought is due in part to the quality and frequency of intellectual stimulation received from adults.

> The formation of operations always requires a favorable environment for "co-operation," that is to say, operations carried out in common (e.g., the role of discussion, mutual criticism or support, problems raised as the result of exchanges of information, heightened curiosity due to the culture influence of a social group, etc.). (Piaget, 1972, p. 5)

Phillips (1975) explored the implications of social interaction, or "sociality," in the development of logical thinking:

> Social interaction has implications beyond itself--notably in the development of logical reasoning. For "reasoning is always a demonstration," and until the child is aware of a need for demonstration, he makes little progress toward developing that ability. Merely interacting freely with his physical environment results in some awareness of gaps and inconsistencies in this thinking, but what really brings them into focus is the difficulties that arise when he attempts to communicate his thoughts to others. (Phillips, 1975, p. 108)

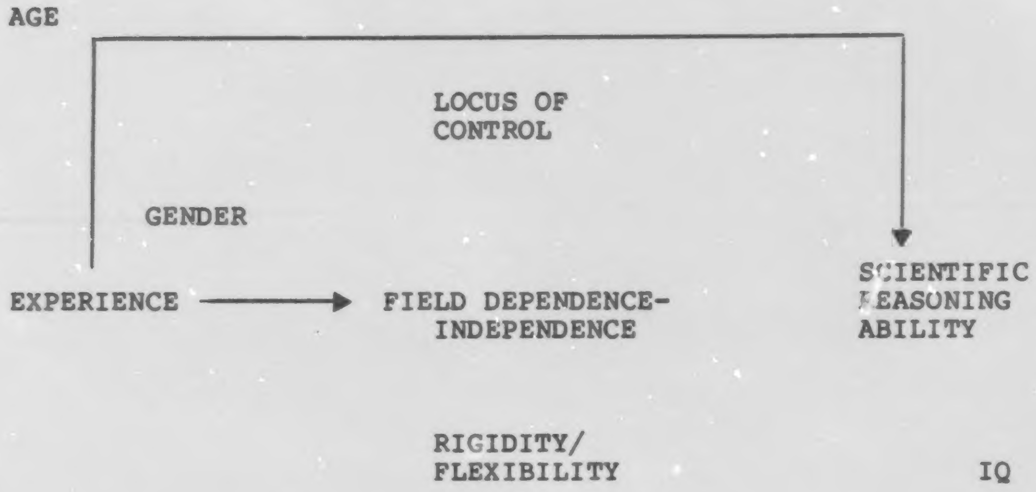

AGE
LOCUS OF CONTROL
GENDER
EXPERIENCE
FIELD DEPENDENCE-INDEPENDENCE
SCIENTIFIC REASONING ABILITY
RIGIDITY/FLEXIBILITY
IQ

Fig. 2-1. A causal model for scientific reasoning ability highlighting the proposed relationships between experience (as the independent variable) and the dependent variables of field dependence-independence and scientific reasoning ability.

Phillips also interpreted Piaget on the subject of sociality:

> Piaget sees social interaction among peers as the best opportunity for childish egocentrism to be overcome through the process of coordinating various points of view. .... Opposition of wills, of children's clashes, are the most fruitful for overcoming their egocentrism. ....Much social interaction concerns the achievement of common goals. If a child has an idea about how he and his companions might advance toward such a goal, he can communicate it to them only by taking their frames of reference into account. He must decenter--recognize his own immediate perspective as one of many (Phillips, 1975, pp. 145-146).

Mooney associated the development of the awareness in the child of the ""I" and the "me," with an awareness of the relationship between his acts and their consequence; of being "taught" by events, and that, in communicating with adults who are at a stage further on in their conscious exercise of "teaching-learning ways to operate," a child becomes equipped to pick up "more deliberate and more self-owned ways to conduct himself to benefit from the way he's made" (Mooney, 1980, p. 319).

The construct of locus of control was chosen as the educative, "teaching-learning" (Mooney), "social transmission" (Piaget) variable for the present study. The following passage explains a basic tenet of the theory out of which the construct of locus of control was built: that the individual's locus develops as a result of his or her significant social transactions with others.

> The dependence of young children upon others for instrumental help and emotional support is, of course, a necessary condition of early development. However,

> the resolution of dependence on such caretakers and the concomitant acquisition of independent problem-solving techniques are equally important requisites of normal personality development. It would not be surprising, then, to find that infants and preschool children--if they could report such beliefs--would ascribe reinforcement responsibility to the powerful others in their environment. But with age and experience, most children should begin to feel that their own actions are often instrumental in attaining the reinforcements they receive. (Crandall, Katkovsky and Crandall, 1965, p. 94)

The construct of locus of control points to the child's conviction that he himself, rather than other persons, is the major cause of the reinforcements (praise, criticism, success, failure) that follow his performance in a particular situation. The construct was developed by Rotter (1966) out of social learning theory to explain the variability in the belief of individuals that their actions produce the reinforcements which follow their efforts, or that the rewards and punishments meted out to them are at the discretion of powerful others or are the result of luck or fate. Crandall et al. (1965) explained that the same reinforcement in the same situation may be perceived by one individual as within his own control (i.e., if his locus of control is internal) and by another as outside his own influence (if his locus of control is external). These same authors speculated that personal beliefs could be important determiners of the reinforcing effects of many experiences, arising out of earlier and continuing social transactions with other individuals.

## Development of the Intellectual Achievement Responsibility Questionnaire As a Measure of Locus of Control

Locus of control was measured in children before the development of the Intellectual Achievement Responsibility Questionnaire (IAR) by two instruments: the Locus of Control Scale, which was developed by Bialer and Cromwell in 1962, and the Children's Picture Test of Internal-External Control, which was devised by Battle and Rotter in 1963. Crandall et al. (1965) discussed the role of these instruments, making conclusions regarding reinforcement responsibility and its relationship to a number of demographic variables, attitudes, and behaviors. When the Intellectual Achievement Responsibility Questionnaire was developed, Crandall et al. explained that their aim was to measure beliefs in internal versus external reinforcement responsibility within the context of children's achievement development, exclusively in intellectual-academic settings. These authors also explained that their instrument differed from other assessment methods in the external environmental forces described:

> While previous scales include a variety of sources and agents such as luck, fate, impersonal social forces, more personal "significant others," etc., the IAR limits the source of external control to those persons who most often come in face-to-face contact with a child, his parents, teachers, and peers. (Crandall et al., 1965, p. 93)

The authors also explained that one of the reasons this restriction was imposed in the development of the IAR was that it seemed important, from a developmental point of view, to focus primarily on children's beliefs in the instrumentality of their own actions compared with that of other people in their immediate environment.

Finally, Crandall et al. explored their suspicion that the dynamics operative in assuming credit for causing good things to happen might be very different from those operative in accepting blame for unpleasant circumstances. The possibility that belief in personal responsibility for the two kinds of events may develop at different rates, or that this may be so for some children but not others, led to the construction of the instrument with a total I (internal responsibility score) and separate subscores for internal responsibility for successes (I+ score) and for failures (I- score).

## Locus of Control and Field Dependence-Independence

The similarities between the cognitive style of field dependence-independence and locus of control have been noted by a number of workers, including Witkin et al. (1977), who originally developed the construct of field dependence-independence. Similarities between the two constructs are summarized below:

> While measures of field dependence are not derived from expectancy statements as is locus of control, the behavioral referents of both constructs appear to be similar. Assertiveness, the experiencing of oneself as a distinct source of causative powers, and the tendency to be "individual" or self-reliant rather than acquiescent and conforming would seem to characterize both the internal and the field-independent individuals. (Lefcourt and Telegdi, 1971, p. 53)

Yalom (1980) suggested imagining a continuum with field dependence and external locus of control on one pole and field independence and internal locus of control at the other. Yalom correlated extreme positions on either end of the continuum with clinically evident psychopathology. Other behaviors correlating with these positions have been explored by Phares (1976) and Lefcourt (1982). These authors summarized research efforts which explored interactive relationships betwen the two variables with a broad span of criterion behaviors, including behaviors associated with cognitive activity. Some of those and other studies are described below because of their emphasis on the relationship between locus of control and field dependence-independence and/or because of evidence for the existence of a causal relationship between the two variables.

Crandall and Lacey (1972) attempted to identify field dependence-independence as an intermediate skill which might account for the superior academic performance of elementary school children who had been identified as internal in their locus of control. When the effects of age and IQ were partialled out of the internal-field independent relationships, prediction in academic performance was reduced for males but not for females. Crandall and Sinkeldam (1964) found that a relationship between social dependence and perceptual field dependence was not substantiated in small children, but that achievement behaviors did predict performance on the Embedded Figures Test, a measure of field dependence-independence, even when the effects of age and IQ were partialled out. These authors suggested that the embedded figures situation, like many other testing and experimental situations, provided cues relevant to children's achievement motivations and behaviors, and "should be so considered in future research" (p. 21). Lefcourt and Telegdi (1971) explored the extent to which internal and external control subjects differed in their general cognitive activity in conjunction with the rod-and-frame measure of field dependence. Significant interactions between locus of control and field dependence were obtained. Internal-field independent subjects scored highest; but in contrast to expectations, the external-field dependents did not score lowest. The theoretically incongruent groups (external-field independents and internal-field dependents) scored lowest. Willoughby (1967) explored the relationship between field dependence-independence and locus of control with 76 undergraduates, using the Hidden Figures Test as a measure of field dependence-independence and the Adult's Locus of Evaluation and Control Scale. Willoughby found statistically significant correlations between field independence and the "evaluation" subscale of the locus of control scale, but the "control" subscale was not significantly related to performance on the measure of field dependence-independence.

A significant negative correlation between the field dependence score and the frequency of guessing indicated that field-dependent subjects may have been less cautious in answering Hidden Figures Test items than the field-independent subjects. Willoughby suggested that these findings indicated that "one of the correlates of perceptual dependency is an increased reliance upon others for self-definition or differentiation" (p. 672).

Generally, the consensus appeared to be that the internal-external orientation of subjects in some way affects their cognitive activity, with consistent differences in behaviors as described below:

> Throughout most of the research described above, evidence has been presented that supports the assumed relationship between locus of control and cognitive activity. Whether the focus has been on attention, deliberation, inquisitiveness, or utilization of information, internals have more often been found to be active and alert individuals than have externals. Sometimes the differences between internals and externals have varied with the ostensible qualities of the task or have occurred only in combination with other measures. Nevertheless, an internal locus of control seems to be a sine qua non of being able to steer one's self more clearly and appropriately through the vagaries and confusions of different situations. (Lefcourt, 1976, p. 60)

It is on this basis that the hypothesized causal relationship with locus of control acting as a determinant of field dependence-independence is posited.

## Locus of Control and Scientific Reasoning

It logically follows that a child who can appropriately attribute his own reinforcement responsibility in situations which warrant that situation may build mental structures which enable him or her to identify cause-and-effect relationships and thus acquire higher-level mental operations more effectively than children who attribute reinforcement responsibility to parents, teachers, and peers. Research reviewed in Chapter Five, "Locus of Control and Cognitive Activity" (Phares, 1976), indicated that locus of control correlates with the kinds of cognitive activity that should facilitate the maintenance of personal causation. Phares speculated that an individual wishing to know about himself, his capabilities, his limits, and his potentialities should seek out situations in which it is possible to test his mettle. Phares' reference to persons who customarily seek out these kinds of situations as "open to experience," "non-defensive," and "self-actualizing" is reminiscent of theoretical positions of both Maslow and Mooney. As well, Phares stated that the idea of locus of control being related to rational cognitive activity appeals to common sense; and that persons holding internal control expectancies should be more cautious and calculating about their choices, involvements, and personal entanglements than are individuals with external control orientations.

> Otherwise [he reasons] the probability of internals being able to regulate their experiences would be lessened. This loss, in turn, would diminish the degree to which they are able to remain actors rather than pawns of fate. Such self-direction should entail more active, cognitive processing of information relevant to the attainment of valued ends, and should be reflected in the types of strategies that characterize an individual. (Phares, 1976, p. 61)

Various forms of cognitive activity were reviewed by Phares, including information assimilation, attention, psychological differentiation, sensitivity, and academic performance. A study which has examined cognitive activity closer to scientific reasoning and has actually used the Intellectual Achievement Responsibility Questionnaire was conducted by Linn, Pulos and Gans (1981), who examined locus of control with a number of ability measures and personality dimensions, in exploring the relationship of these variables with the particular scientific schema of controlling variables. Linn et al. hypothesized that among the independent variables, locus of control would be associated with formal reasoning, i.e., three controlling variables tasks with different content and two question-type tests dealing with analysis and controlling questions. In seventh-grade students ($n$=120), results of a regression analysis for each problem and all tasks revealed that general ability, field dependency, and locus of control were consistently and significantly related to the controlling questions. Linn et al. justified these results by reasoning that "Since internals perceive tasks as under their own control, they are more likely to attend to and utilize the information in the tasks than externals" (p. 439).

### Hypothesized Relationships Concerning Locus of Control As an Independent Variable

From extensive reading in the area of locus of control and its relationships to cognitive activity, as well as the study described above (Linn, Pulos and Gans, 1981), it was hypothesized for the present research that a relationship exists between internal locus of control and field dependence-independence, and between internal locus of control and scientific reasoning ability. Figure 2.2 highlights those relationships.

## C. Age

### Age and Experience

Common sense points to the fact that, as one increases in age, more and more experiences become available from which one draws to make generalizations and predictions concerning future events. Mooney generalized this notion by saying that through a number of years of experience, a person gets a clearer perspective of the "time-space position from which he composes and speaks," and that with more experience, more sorting occurs so that generalizations emerge. Piaget's model for cognitive development is age-dependent, with age (most often discussed by Piaget as

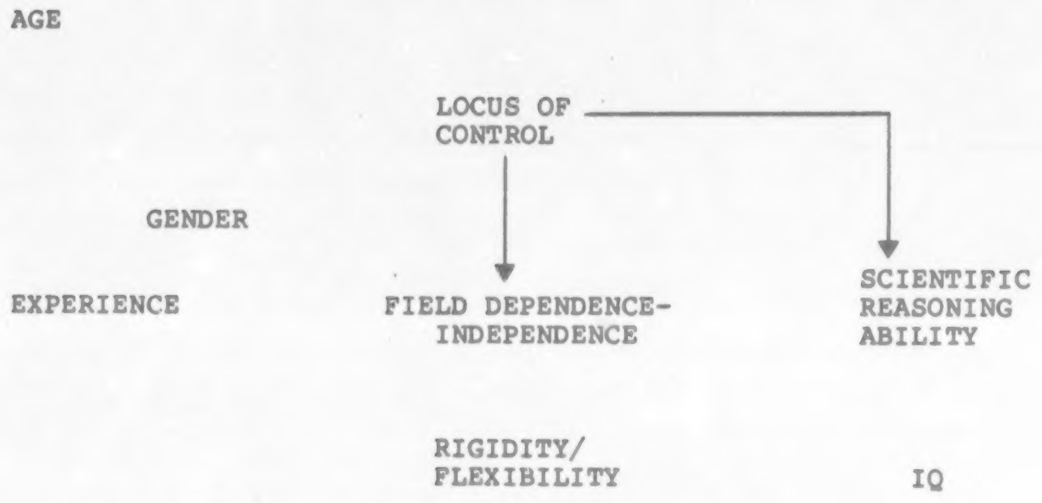

AGE
LOCUS OF CONTROL
GENDER
EXPERIENCE
FIELD DEPENDENCE-INDEPENDENCE
SCIENTIFIC REASONING ABILITY
RIGIDITY/ FLEXIBILITY
IQ

Fig. 2-2. A causal model for scientific reasoning ability highlighting the proposed relationships between locus of control (as the independent variable) and the dependent variables of field dependence-independence and scientific reasoning ability.

"maturation") a necessary factor, along with a number of others, in the process of formal thought attainment. A number of persons (e.g., Kahle, 1983; Maccoby and Jacklin, 1974; Treagust, 1980) working in areas of cognition stress that the choice of experiences which may enhance rational thought development becomes a very important determinant of ultimate cognitive development. Preferences for experiences which involve actions upon concrete objects and visual specialization are more evident at the age of adolescence than at earlier ages. Children during adolescence exercise more independence and specialization in choosing pastimes out of school and coursework within the context of the school curriculum; and as these children pass through adolescence into adulthood, patterns of activity become more consistent. As well, during adolescence children also have choices concerning coursework within the context of the school curriculum, which are largely unavailable to children at younger ages. The ageing which occurs throughout adolescence is thus quite dramatic in terms of choices of activities, pastimes, and coursework, including those which involve mental restructuring and spatial visualization.

## Age and Rigidity/Flexibility

Within the framework for the present research, outlined previously as embracing a model of man as full-functioning and self-actualizing, it appeared that an increase in flexibility, or tolerance for ambiguity, occurs normally from childhood to adulthood. Frenkel-Brunswik (1949) stated that the individual intolerant of ambiguity tends to arrive at premature closure, often at the neglect of reality. Flexible individuals are able, given a particular event which induces cognitive conflict and need for resolution, to act upon that event so that closure is met, but not prematurely. The ability to act upon ambiguity as a decentered individual has been used as a sign of cognitive maturity (see theoretical discussions by Piaget, 1973, and Phillips, 1975); and acting upon ambiguity by demanding premature closure has been shown in adolescents to be a sign of cognitive immaturity in young adolescents (Lunzer, as discussed in Wollman, Eylon, and Lawson, 1980). In school children in grades 1 through 6, Breskin (1969) found that rigidity as measured by Breskin's Rigidity Test decreased in both boys and girls from grade 1 to grade 6. On these bases, the proposed relationship between age and rigidity/flexibility was hypothesized.

### Age And Scientific Reasoning

Exclusive of the social and environmental experiences operating on the individual during development, physical and physiological changes also occur within the organism. It has been conceptualized and empirically supported by a number of educational theorists and practitioners (e.g., Case, 1975, 1979; Epstein, 1974; Inhelder and Piaget, 1958;

Pascual-Leone, 1970; Taba, 1962) that associated with the maturation of the human individual are particular orderly and sequential changes which enable the ability of the organism to adjust, involving the whole individual reacting to his entire environment. Further, Taba (1962) stressed the interrelatedness of the different dimensions of growth (e.g., physical growth, social growth, emotional growth, mental growth) "Emotional development affects mental growth because emotional factors facilitate or block such mental activities as language and reasoning" (Taba, 1962, p. 90).

The interrelations of maturational features with other aspects of development were discussed by Piaget, views of which are summarized by the following passage:

> First factor: heredity, internal maturation. This factor can certainly be retained from every viewpoint, but it is insufficient because it never occurs in the pure or isolated state. If a maturation effect intervenes everywhere, it remains dissociable from the effects of the exercise of learning or of experience. Thus heredity is not a factor which acts alone or which can be isolated psychologically. (Piaget, 1972, p. 27)

Although the preceding passage underscores the notion that maturational level alone is not responsible for the development of cognitive abilities, a number of research studies relating to cognitive ability which include a maturational variable indicate the strength of this variable in predicting the acquisition of formal reasoning schemata.

Brain growth as a maturational variable affecting cognitive development was discussed by Bybee and Sund (1982), with particular reference to the brain growth studies of Epstein (1974a, 1974b). Epstein found that the brain increases significantly in weight at certain times of life and hardly at all at other times. His research also revealed that the periods of brain mass increase occurring in approximately 85 percent of all children corresponded to the following age spans: (1) 3-10 months; (2) 2-4 years; (3) 6-8 years; (4) 10-12 years; (5) 14-16+ years (earlier for girls). Bybee and Sund suggested that these increases--except for the fifth one--correspond to the Piagetian stages of cognitive development. Implications for enhancement of cognitive development during these periods are also discussed by Bybee and Sund.

Carpenter (1980) discussed the viability of the information-processing model proposed by Pascual-Leone (1970) and applied to Piagetian theory by Case (1975, 1979). Capacity of the central processor or "working memory" is the principle focus of the information-processing model. Case (1979) modified the Piagetian position of "internal maturation" by postulating that "the general factor in development (that is, the factor transcending the present or absence of any specific structure) is best conceptualized as a quantifiable level of working memory" (Case, 1979, p. 92). The basic number of schemes, rules, or ideas that a child can handle simultaneously is a capacity that increases with age, and the maximum number of "chunks" of information that a child can integrate simultaneously is assumed to grow linearly in an all-or-none manner as a function of age (Carpenter, 1980). It was postulated by Carpenter that "working memory" increases from the age of 3-4 years at the rate of one chunk every two years until the late formal operational stage (about 15-16 years).

Bybee and Sund (1982) used the Epstein evidence to suggest that brain growth may indicate level of cognitive development; Case (1979) and Lawson and Renner (1975) appeared to prefer an information-processing model, in which the working memory capacity may place a constraint on the child's ability to store and mentally manipulate information and thus place a constraint on his ability to comprehend complex conceptualizations.

Grade level and chronological age, much simpler measures of maturation, have been shown to predict the attainment of formal reasoning schemata. For example, Lawson and Renner (1974) quoted percentages of concrete, post-concrete, and formal children in grades 7-12 (n=588) on Piagetian interview tasks which showed a trend towards increase in percentage of formal thinkers with higher grade level: 17%, 23%, 18%, 27%, 29%, and 34%, in grades 7 through 12, respectively. Using another high school sample, (n=134), results were also quoted (Lawson and Renner, 1974), for numbers of students at the formal level in three science areas with differing means in age: biology (age $\bar{X}$=16.4 years), 35%, chemistry (age $\bar{X}$=17.3 years), 78%; and physics (age $\overline{X}$=17.9 years), 64%. Rowell and Hoffmann (1975) used an Australian high school sample (n=193), with two sets of data from group tests on the Piagetian Pendulum Problem and Chemical Problem. Their results also showed an increase in the percentage of formal thinkers with increase in chronological age as measured in months. In the process of validating the Lawson test (Lawson, 1978), eighth, ninth, and tenth grade students (n=513) with mean ages of 14.1, 15.2, and 16.5 years, respectively, scored 5.68, 7.46, and 8.04 on the Lawson Test of Formal Operations, which had a range of 0-15 in score. These results also can be used to hypothesize the predictive value of age on scientific reasoning ability.

## Hypothesized Relationships Concerning Age As an Independent Variable

From studies chosen for review to explore age as an independent variable, these relationships are hypothesized: between age and experience, with higher ages predicting more experience in mental reformulation and spatial visualization; between age and rigidity/flexibility, with higher ages predicting higher flexibility; and between age and scientific reasoning ability, with higher ages predicting high scores on the measure of scientific reasoning. Figure 2.3 highlights these relationships.

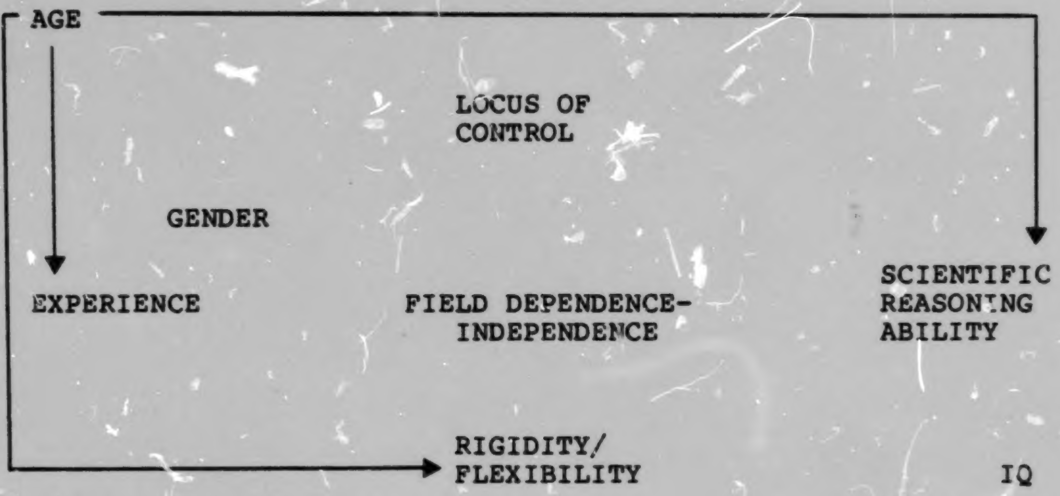

AGE
LOCUS OF CONTROL
GENDER
EXPERIENCE
FIELD DEPENDENCE-INDEPENDENCE
SCIENTIFIC REASONING ABILITY
RIGIDITY/FLEXIBILITY
IQ

Fig. 2-3. A causal model for scientific reasoning ability highlighting the proposed relationships between age (as the independent variable) and the dependent variables of experience, rigidity/flexibility and scientific reasoning ability.

## D. Field Dependence-Independence

### Theoretical Considerations

Cronbach and Snow (1977) defined "aptitude" as ..."any characteristic of a person that forecasts his probability of success under a given treatment" (p. 6), and further stated that "any aspect of the individual, including some matters untouched by conventional ability and personality measures, can predict a response to instruction and hence can be a source of 'aptitude'" (p. 6). The question then became one of examining individual traits or aptitudes which may, under a specific manipulable variable, identified as treatment (Cronbach and Snow suggest pace, method, style of instruction, classroom environment, students'experience), differentially predict success in the acquisition of scientific reasoning abilities.

A description of the role of perception in life experiencing as the "organizer of experience," lying "at the crucial point where man and environment are joined in a common field" (Mooney, 1980, p. 65) suggested that an aptitude variable which depicts the manner in which an individual conceptually organizes experience may be found within the hypothetical construct of cognitive style. Goldstein and Blackman (1978) distinguished cognitive style as a mediating variable which emphasizes the structure rather than the content of thought, therefore referring to the ways in which individuals conceptually organize their environment. In their book, Goldstein and Blackman (1978) reviewed in detail five approaches to the study of cognitive style. Based upon the S-O-R model, a rationale is provided for cognition as a mediating process between organism and environment, based upon the current cognitive-learning perspective that the organism responds to its cognitive construction of the environment rather than to objective reality.

One approach considered by Goldstein and Blackman (1978) was field dependence-independence, a measurement of cognitive style based upon the study of perceptual differences in individuals. Using a variety of instruments in his early research, H. A. Witkin from 1942 to the late 1970's broadened the construct to include many dimensions of personal functioning, including body concept, the nature of the self, and defenses. In the course of his work, Witkin broadened a view of field dependence-independence of performance on experimental tasks having to do with the perception of the upright as measured by the Tilting-Room-Tilting Chairs Test and the Rod and Frame Test to include the ability to locate an object within an embedding context (as measured by various forms of the Embedded Figures Test).

## The Concealed Figures Tests as a Measure of Field Dependence-Independence

A version of the kind of test which measures the ability of an individual to locate an object within an embedding context is the Concealed Figures Test (Thurstone and Jeffrey, 1956), which was chosen for the present study as a measure of field dependence-independence for a number of reasons, including the concurrent validity with other paper-and-pencil measures of field dependence-independence, the group mode of administration of the test, and its suitability for subjects within the age range of the present study.

## Field Dependence-Independence and Scientific Reasoning Ability

Weisz, O'Neill and O'Neill (1975) compared a number of personological variables to distinguish between cognitive ability and cognitive style in children of two chronological ages (CA): 9 years and 12 years. Level of cognitive ability, or mental age (MA), was measured by the Picture Vocabulary Test. Also examined were subjects' Rorschach structuring ability and field dependence, as measured by the Children's Embedded Figures Test (CEFT). A 2 x 2 (CA vs. MA) analysis of variance performed on the CEFT and the two Rorschach variables showed significant improvement with MA. The CA effect did not approach significance on any dependent variable. Weisz et al. also found that MA was a stronger developmental correlate than CA or IQ, of both Rorschach structuring ability and field dependence. When MA was partialed out, a significant correlation remained between Rorschach developmental level and the CEFT, providing some support for the cognitive style variable in Witkin's theory. The CEFT-Rorschach correlations were found to be substantially lower than the CEFT-MA correlation, a finding which suggested to the authors that cognitive style theorists should be aware of the need to differentiate between proposed traits of cognitive style and of cognitive developmental level.

Niemark (1979) identified field dependence-independence as an index of cognitive style which could be used to differentiate formal from nonformal operational thinkers. Niemark summarized research on individual differences in this way: "In all cases style differences reported are consistent with the general characterization of the formal operational thinker as more reflective, analytic, field independent, active, systematic, and original" (p. 63).

Pascual-Leone (discussed in Niemark, 1979, and in Adi and Pulos, 1980) also identified the cognitive style of field dependence-independence as a dimension of importance in formal operational thought. An analysis showed that this cognitive style dimension affected the outcome where two strategies were in conflict: the strategy that has been used in the past, and the other strategy which must be constructed. Pascual-Leone found that the former strategy is considered first by both field-dependent and field-independent subjects, but only the field-independent subject moves on to consider or to construct an alternative strategy.

Adi and Pulos (1980) investigated the relationship between formal operational performance and specific individual traits of college students. Using a modified group test of the Gottschaldt Figures Test (another measure of field dependence-independence) Adi and Pulos found that field dependence-independence was significantly correlated with formal operational performance on a specific conceptual schema, proportions, as measured by the Equilibrium in a Balance Test, a paper-and-pencil test administered in a group setting. A stepwise regression analysis was also performed with the order of entry of the independent variables other than field dependence-independence determined by the magnitudes of the partial correlation coefficients with the dependent variable. Field dependence-independence was entered into the analysis as the first of five independent variables, and the analysis indicated that significant increases in prediction occurred only when sequential reasoning was subsequently entered. Twenty-nine percent of the variance in formal thought was accounted for by field dependence-independence, and 11% of the variance in formal thought was accounted for by sequential reasoning with the effect of field dependence-independence removed.

Linn, Pulos and Gans (1981) explored field dependence-independence within a set of ability and personality factors in a study which examined content and problem effects of three controlling variables tasks with different content and two question-type tests (analysis and controlling questions). Field dependence-independence was one of the variables found to be consistently and significantly related to the controlling questions across all three tasks, and it was the only variable found to be related to the analysis question.

These results and other generalizations reported by Nagy and Griffiths (1982) contradict an early review by Vernon (1972) on the unique contributions of the construct of field dependence-independence. Vernon quoted results from his own research that most correlations with field independence, when intelligence was held constant, were found to be within the domain of interests rather than personality traits or independent, mature thinking.

### Hypothesized Relationships Concerning Field Dependence-Independence As An Independent Variable

On the basis of the more recent work reported above concerning the value of field dependence-independence in predicting formal operational thought, the relationship is hypothesized that individuals who are field independent will have higher scientific reasoning abilities. Figure 2.4 highlights that relationship.

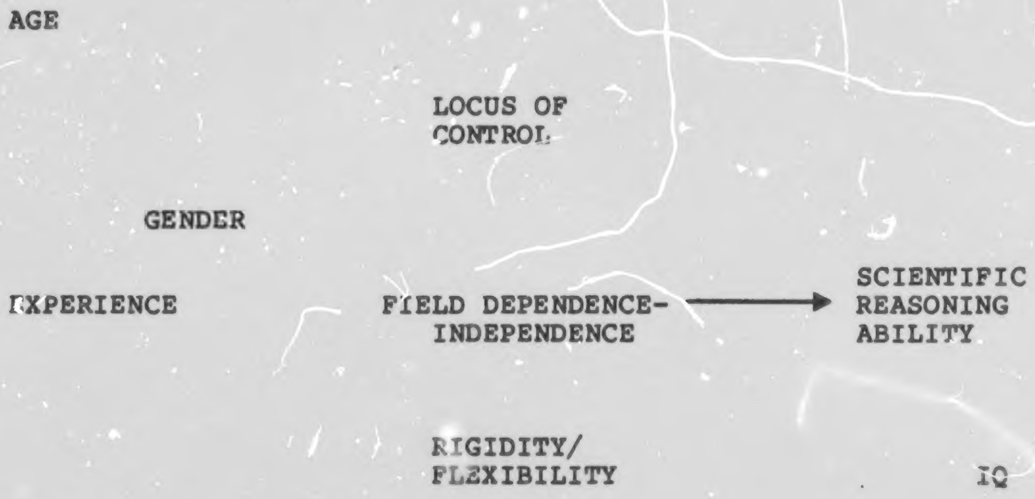

AGE
LOCUS OF CONTROL
GENDER
EXPERIENCE
FIELD DEPENDENCE-INDEPENDENCE
SCIENTIFIC REASONING ABILITY
RIGIDITY/ FLEXIBILITY
IQ

Fig. 2-4. A causal model for scientific reasoning ability highlighting the relationship between field dependence-independence (as the independent variable) and scientific reasoning ability.

## E. Flexibility/Rigidity

### Theoretical Considerations

Assuming that the basic nature of reality is change, movement, and development, Ross L. Mooney proposed the Self-in-Situation model of human functioning, in which intrapersonal transactions were described which move on to interpersonal transactions, extending beyond to a rhythmic relationship with the universe in both a physical and a metaphysical sense. At the center of the entire process is a personal willingness to experience self (body, mind, and emotions) and other elements of the universe; and to formulate meanings from those experiences which, in turn, refashion the "inner world," the actual composition of body, mind and emotions, as well as the "outer world," environment and universe. The model is that of microcosm and macrocosm, addressing the primary cellular-structural integrity of the individual, moving rhythmically "outward" into the world and the universe beyond, then back again, then outward again, ad infinitum.

Mooney depicts the human mind as a life-and-growth-producing instrument, serving as a mediating link between what man is, inside, and his outside environment. "It is a means to which to work the fittings out between the orderings inside and out" (Mooney, 1980, p. 318). Internalized within the man, the system works to seek adaptiveness, and is thus equipped to operate as a generalized problem-solving instrument. "The price is that he, himself, is required to know what fits, and then to act responsively" (Mooney, 1980, p. 318), results of which indicate how rationally the individual perceives and responds to the perception.

Mooney's interactive model of man suggests by description the elusive equilibration mechanism of Piaget's model for cognitive development, the "ineluctable rhythm" used to explain the mechanism by which an individual experiences the environment, acts upon that experience, and takes that experience into himself. Either by assimilation or accommodation, the individual them modifies or replaces pre-existing mental structures. Flavell (1977) explained Piaget's view of human cognition as a "specific form of biological adaptation of a complex organism to a complex environment." Flavell continued with a description of the Piagetian man: an individual who "actively seeks and interprets environmental information in the construction of 'his own knowledge' rather than passively copying the information just as it was presented to his senses" (Flavell, 1977, p. 37). As well, Flavell pictured the individual as paying attention to and taking account of the structure of the environment during knowledge seeking, as well as always reconstructing and reinterpreting that environment to make it fit with his own mental framework.

Piaget speaks of equilibration in The Child and Reality:

> I would like to speak of a fourth factor which I will call the factor of equilibrium. From the moment when there are three factors, there must already be a balance among them; but further, in intellectual development, a fundamental factor intervenes. The fact is that a discovery, a new notion, a statement, etc., must balance with the others. A whole play of regulation and of compensation is required to result in a coherence. I take the word equilibrium not in a static sense but in that of a progressive equilibration, the equilibrium being the compensation by reaction of the child to the outer disturbances, a compensation which leads to the operatory reversibility at the end of this development. (Piaget, 1973, p. 29)

A more explicit description of the actual mechanism of equilibration is lacking in Piaget's writing, commented as being a "serious omission" (Bybee and Sund, 1982) and "rather vague," "somewhat incomprehensible" (Wollman, 1978) account of the mechanism controlling the acquisition of new schemata. Block (1982) chose to redefine equilibration along psychological lines, suggesting that mediating variables in the form of personality or cognitive style may affect the manner in which an individual approaches situations of cognitive disequilibrium. Block speculated that some persons, in reaction to new experiences which fail to conform to the expectations generated from existing schemas, are able to (and even insist on doing) encompass the new information in ways that require little or no modification of previously established premises. Other persons encountering discrepant experiences have a greater readiness (and even preference) for leaving schemas that do not mesh readily with the new information and move on to the formation of new and sufficient meaning-making structures. Block suggested that individual differences in reacting cognitively to discrepant experience may thus have the effects of enhancing, retarding, or blocking the development of logical mental structures.

Piaget also suggested that a personological construct (i.e., the "coordinating activities peculiar to the subject" in the passage below) plays an important role, perhaps the "deepest source" in the development of logical schemata:

> The basic relation of stimulus and of response, even if we retain such a term, as well as the associations of stimuli and of responses, could not be interpreted therefore in the sense of an exclusive submission of the subject to the object. Certainly this submission exists, and even reinforces itself during development, but it is possible only because of the intervention of coordinating activities peculiar to the subject and which, in the last analysis, constitute the deepest source of the logical structures. In short, the object is known only so far as the subject achieves action on it, and this action is incompatible with the passive character which empiricism, at various degrees, attributes to knowledge. (Piaget, 1973, p. 107)

The term "rigidity/flexibility" was used in the present research to represent a personological variable depicting openness to experience, suggestive of Mooney's rhythmic self-in-situation model and Piaget's "ineluctable rhythm." An author who has written extensively on the interrelations among personality, belief, and cognition as they relate to an individual's rigidity or "intolerance of ambiguity" is

Frenkel-Brunswik (1949). Her main thesis, which was derived from psychoanalysis, was that there exists a close correspondence between the cognitive spheres of behavior on the one hand and the emotional and social spheres on the other. Frenkel-Brunswik started with the psychoanalytic concept of emotional ambivalence and the role that it plays in the development of the child's personality structure. She then developed the notion that as a result of early parent-child relations involving varying degrees of permissiveness or punitiveness there emerge individual differences in the ability to tolerate emotional ambivalence towards parents which, in turn, "spill over" into the social and cognitive spheres as well. Thus, a person who, through punishment, is not permitted to express his normal ambivalence feelings toward his parents develops a generalized need to structure his world rigidly, a pervasive tendency to premature closure and a general intolerance of cognitive ambiguity.

## The Breskin Rigidity Test As a Measure of Rigidity/Flexibility

The measure for flexibility/rigidity chosen for the present research was a non-verbal test which was constructed and validated by Stephen Breskin (1968). The design of the Breskin Rigidity Test (BRT) was based upon experimental findings which suggested to the author that the use of a perceptual rather than a conceptual frame of reference might indicate the rigid individual who requires "a greater degree of structure in his environment" (Breskin, 1968, p. 1203). Breskin (1968) explained that many other tests for rigidity have characteristically been of the verbal or problem-solving type. Breskin chose to construct a non-verbal test based upon the work of Fisher, Frenkel-Brunswik, and Luchins, in which ethnocentric/authoritarian persons were examined in relation to their tolerance for ambiguity. Breskin's rationale follows:

> Fisher in 1951 hypothesized that "... breaking the gestalt or altering the course of Praegnanz and its properties is more characteristic of non-ethnocentric than ethnocentric people." Comparing two such groups, Fisher concluded that with respect to the law of Praegnanz, ethnocentric people are less inclined to alter the "gestalt course" and more inclined to seek it when in fact it is not present. Frenkel-Brunswik (1949) has examined the authoritarian person in relation to ambiguity. She states that the individual "intolerant of ambiguity" tends to arrive at premature closure as to valuative aspects, often at the neglect of reality. In a study by Luchins it was found that Ss differentiated as "more rigid" demonstrated a greater tendency toward closure than "less rigid" Ss when given the task of assessing at what point two approaching halves of a circle appear to be a circle. (Breskin, 1968, p. 1203)

Breskin further postulated that a requirement for structure would be manifested in the use of the Gestaltist law of Praegnanz, i.e., a more rigid person, given the opportunity to express a preference between pairs of figures differing only in "goodness of fit" will tend to select the "better" fit. Marx and Hillix (1979) explain that Praegnanz is one of the principles of perceptual organization, originally put forth by the Gestalt psychologist Wertheimer in 1923. Included within the principles of proximity, similarity, direction, objective set, and common fate is the principle of Praegnanz, which states that figures are seen in as "good" a way as possible under the stimulus condition. The example is given of gaps in a figure which are frequently closed perceptually by an individual because the resulting figure is more closed or "pregnant." A good figure is one which cannot be made simpler or more orderly by a perceptual shift.

In this regard, Breskin chose pairs of common abstract visual symbols constructed such that one symbol adhered closely to the Gestalt course, while the other clearly violated the canons of Praegnanz. For each pair, the subject was instructed to choose one of the figures which he liked better. A rigidity score was taken to be the total number of Praegnanz items selected. The test was validated using the method of contrasted groups: art students vs. accounting majors and secretarial students. Breskin reported that art students were less rigid than the latter group and that males were more rigid than females. The latter finding was supported in a follow-up study which extended the norms for the BRT to elementary school children (Breskin, 1969).

## Rigidity/Flexibility and Field Dependence-Independence

Conforming to the humanistic model of full functioning as adopted in the present research was the proposition that flexibility leads to the more abstract cognitive structures identified with field independence. Results from a number of studies reviewed by Breskin and Gorman (1969) tended to confirm the hypothesis that field-dependent persons are more rigid than field-independent persons. Witkin et al. (1977) cited numerous personality traits presumed to be associated with field dependence-independence. One of these traits said to be related to field dependence was rigidity in cognitive functioning. A similar relationship was noted by Gardner, Holzman, Klein, Linton, and Spence (1959). The results of their research revealed a close relationship between field dependence-independence and a personality variable called constricted-flexible control was found to exist. However, the relationship between these variables was found to exist only in women, not in men. Similar results were also found in a later study by Breskin and Gorman (1969), using Breskin's Rigidity Test as the measure of rigidity. In this study, the prediction that field-dependent persons would be more rigid than field-independent persons was confirmed, but also only for females and not for male subjects.

This evidence suggests the possibility of differences in males and females with regard to the relationship between these two variables. However, the theoretical model constructed for the present research included a simplified view of this relationship without incorporating gender differences.

## Rigidity and Scientific Reasoning

Phillips (1975) described rigidity in reasoning by the following example:

> The reasoning is by simile: A in like B is some way; therefore, A is like B in every way. (p. 79)

Following this example was this footnote:

> Again, this is a fairly accurate picture of the rigidity that can be found in the thinking of many adults in certain situations (e.g., A and B both have dark skins; B is shiftless and irresponsible, therefore, so is A). Piaget has not dealt extensively with the questions of why adult structures are not always used. .... Or to put it another way (and this is roughly the way Piaget puts it); A is assimilated into B. The child is centering on B, and until he can decenter, his thinking will be characterized by a notable coarseness and rigidity--a lack of refinement and mobility--as compared to the operational thinking of the Concrete Operational Period. (p. 79)

Phillips' interpretation of the relationship existing between rigidity and reasoning conforms to the premise that reasoning follows naturally as a result of the development of more flexible thought.

### Hypothesized Relationships Concerning Flexibility/Rigidity As An Independent Variable

It was speculated in the present research that in individuals who demonstrate rigidity, equilibration may be dictated by preference for unambiguous experience. In situations which would otherwise call for tolerance of ambiguity and reflection, cognitive dissonance may not occur because the individual prefers to act upon experience which is congruent to his preference for unambiguous experience, or as if it were congruent, as suggested by Block (1982). In rigid individuals, experience may be either perceived or interpreted according to the mental structures already possessed by the individual; and new mental structures will therefore not be easily formulated. The hypothesized relationship between flexibility/rigidity and scientific reasoning is that the more flexibile individuals will exhibit higher abilities in scientific reasoning. A relationship between flexibility/rigidity and field dependence-independence is also hypothesized. Figure 2-5 highlights these relationships.

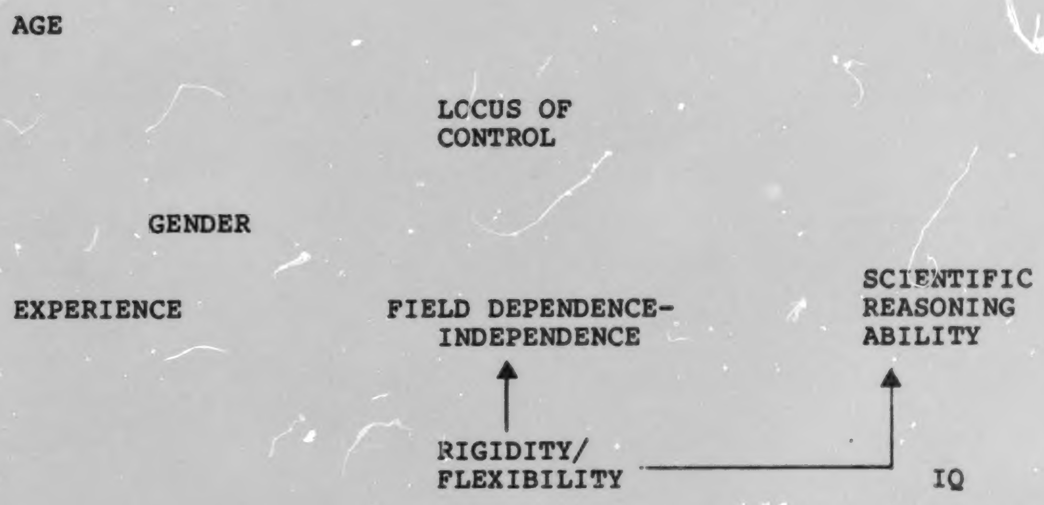

AGE
LOCUS OF CONTROL
GENDER
EXPERIENCE
FIELD DEPENDENCE-INDEPENDENCE
SCIENTIFIC REASONING ABILITY
RIGIDITY/ FLEXIBILITY
IQ

Fig. 2-5. A causal model for scientific reasoning ability highlighting the proposed relationships between rigidity/flexibility (as the independent variable) and the variables of field dependence-independence and scientific reasoning ability.

## F. IQ

### Theoretical Considerations Regarding Intelligence, Ability to Learn, and IQ

Early in the present research, the ambiguity and controversy which exist concerning conceptualizations centering on the terms intelligence, ability to learn, and IQ became obvious. Statements of general concern regarding the restrictive value of intelligence tests were found to be common in the literature. For example, Das, Kirby, and Jarman (1979) argued:

> Intelligence tests should be looked upon as measures of ability and that they do not indicate clearly the intellectual processes whose end products are these abilities. By focusing solely on measures of ability, the essential functions of the mind-- the perceptual, associative and relational functions--have been neglected. (p. 3)

DeVries (1974) stated that IQ tests are not derived from any theory of intelligence but are based, instead, on certain assumptions about intelligence:

> IQ testmakers assume that the more correct answers the child gives relative to others of the same chronological age, the more intelligent he is. IQ is thus defined in terms of individual differences with regard to a wide variety of items which have no theoretical significance in themselves (that is, one cannot conclude anything about a child's general intelligence from his response to a single item. (p. 747)

Broader viewpoints expressed by a number of theoreticians and researchers (e.g., Cronbach and Snow, 1977; Das et al., 1979; Taba, 1962) indicated existence of conflicting issues and need by this author for resolution regarding the terms "intelligence", "ability to learn", and "IQ". The literature reviewed below represents an attempt to resolve some of the ambiguity associated with the term "IQ".

Intelligence.-- Taba (1972) discussed three major issues regarding the nature of intelligence which have been raging for a long time: (1) whether differences in intelligence are hereditary or caused by environmental factors; (2) whether intelligence is constant or modifiable, and (3) whether intelligence is a unitary characteristic or composed of a series of specific abilities.

Regarding issue 1, Taba suggested that, at present, the conceptualization of intelligence reflects that notion that intelligence is a product of an interaction between the environment and heredity and therefore modifiable and not constant.

> If the functioning intelligence is the product of both environmental stimulation and native potential, there is no doubt that providing systematic experience has an influence on developing cognitive organization, and hence on the ability to see relationship, to reason, to solve problems, and to generalize. Until more is known about how concepts and thought are formed, what patterns of thinking are possible under which conditions, and how particular individuals go about forming concepts and organizing cognitive processes, it is difficult to project educational practices which are effectively focused on developing adequately functioning intelligence and productive thinking, especially on its accumulative development. (Taba, 1972, p. 112)

The model for intelligence used in the present study concurs with Taba's conclusions. Employed within the present study was a model consisting of a hierarchial arrangement of abilities, modified by Cattell, from the original model by Spearman. Retained within Spearman's model is a general factor, g, Cattell's "fluid ability," which is described by Cronbach and Snow (1977) as a "complex assemblage of intellectual skills and strategies whose makeup differs a bit from person to person, rather than a unified process or a biological parameter" (Cronbach and Snow, pp. 152-154) but which is distinguished from "crystallized ability" and achievement which depend directly on training. Cronbach and Snow suggested that g is best thought of as a broad composite ability, most probably genetically based, but dependent upon not only native potential but also on motivation and environmental stimulus as well. The functioning of intelligence as an outcome of three variables was discussed in detail by Taba (1962, pp. 103-104), a scheme was offered which suggests that functioning intelligence is conditioned by the native potential but not completely limited by it. A person of high potential intelligence may have low functioning intelligence because of low exposure or low motivation.

The controversy regarding issue 2, whether intelligence is constant or modifiable, was resolved in the present research by adopting a model of intelligence which views intelligence as a product of heredity and environment, with a "fluid ability" and "crystallized ability," respectively; and depending upon (1) native potential, (2) motivation, and

(3) environmental stimulus. The native potential component of intelligence was therefore viewed as constant and thus not modifiable directly; but the motivational and environmental components themselves were viewed as modifiable and thus enhancing native potential.

Historically, theory presents a broad spectrum of viewpoints regarding issue 3, whether intelligence is a unitary characteristic or composed of a series of specific abilities. Cronbach and Snow (1977) explored the range of models concerning the complexity of the domain of intelligence, with models ranging from modest elaborations of the Spearman structure, dominated by a general factor, to the Guilford model, which encompasses a multitude of abilities. Spearman was inclined to interpret *g* as inherited, unitary intellectual power. Thurstone and others challenged the Spearman unitary concept and described seven or more "primary" mental powers. Guilford undertook to catalog abilities, adopting the Thurstone procedures of factor analysis. Guilford's present hypothesis embraces 129 or more abilities, nearly 100 of which purportedly have been identified with distinct test operations (Cronbach and Snow, 1977). Another tack was taken by the British school (Spearman, his American colleagues Holzinger, Burt, Vernon, Cattell, and others). The later models of the original Spearman concept retained the general factor *g* atop a hierarchial system. Placed at the second level are verbal-educational and spatial-mechanical abilities, two major group factors which tie together subordinate group factors roughly analogous to Thurstone's primary abilities. It is from Cattell's model that the concepts of "crystallized" and "fluid" abilities are accepted in the present study to represent the model for intelligence which embraces both genetic and environmental components.

Ability to Learn.-- Cronbach and Snow (1977) stated that "There has always been a loose identification of the concept of intelligence or aptitude with learning rate" (p. 108) and traced the development of an American philosophy regarding the value of intelligence tests in predicting "ability to learn." Cronbach and Snow positively assert that individuals differ in the facility with which they learn, but are also quite aware of the difficulties of research in the area: "While the intuitive concepts of learning ability or abilities and learning rate(s) will continue to be useful, the attempt to give theoretical meaning to them or to reduce them to operational terms is blocked by a number of difficulties" (pp. 107-108).

Although Woodrow in 1946 made a general statement that the ability to learn cannot be identified with the ability known as intelligence, Cronbach and Snow cite later evidence in Chapters Seven through Eleven which "undermine Woodrow's conclusions" by showing that learning tasks often correlate with tested abilities. If that is indeed the case, children who learn easier and/or faster would be expected to develop reasoning patterns earlier than those for whom learning is more difficult. Several studies have explored the relationship between precocity and cognitive development and/or the development of reasoning patterns.

Keating (1975) cited evidence to support the relationship between precocity in cognitive development and psychometrically defined brightness in early adolescents in order to resolve the question of whether high scorers on psychometric tests are not necessarily precocious, but just "good test takers." Fifth and seventh graders classified by psychometric testing as bright and average were evaluated on Piagetian tasks of formal operations. Results indicated that bright groups evidenced formal operations far more frequently than the average groups. Keating concluded that brightness psychometrically defined does imply cognitive developmental precocity within Piagetian theory.

In another study by Weisz, O'Neill and O'Neill (1975), mental age (MA) was found to be a stronger correlate of cognitive development, as measured by Rorschach structuring ability, than chronological age or IQ. When MA was partialled out, the percentage of variance in cognitive developmental level scores accounted for by the Children's Embedded Figures Test (CEFT), a measure of field dependence-independence, dropped considerably. The authors reported that 52% of the CEFT variance was accounted for by its correlation with MA, and the strength of the theoretically important Rorschach-field dependence relationship appeared to derive largely from the mutual correlation of the variables with cognitive developmental level as reflected in mental age.

Ability (i.e., as "ability to learn") was suggested by Cronbach and Snow as an interacting variable in aptitude-treatment-interaction (ATI) studies.

> The regression of an instructional outcome onto a personality trait can plausibly be expected to vary with ability. Rarely has ATI research considered this possibility. Once the suggestion is made that a regression functional for personality within a superior group may differ in location or shape form the same function in a group of lower ability, it becomes "obvious" that that is more probable than improbable. (Cronbach and Snow, 1977, p. 397)

As such, the term "ability to learn" in the present study is recognized as one which may interact with personological variables and thus have implications in the interpretation of research findings for the present study.

IQ.-- For the purposes of this study, IQ was viewed as a frequently used operational, observable, and measurable representation of mental functioning. The IQ score was recognized as a measure of broad composite abilities, most probably genetically based, but dependent as well on motivation and environmental stimuli. To the extent that the IQ test in the present study was a valid measure of intelligence, and provided that the sample selected for testing is representative of the population from which it was drawn, an empirical distribution of IQs were assumed to be similar to the population distribution of intelligence.

IQ and Scientific Reasoning

IQ has consistently been used as an independent variable in studies exploring cognitive development (e.g. Cloutier and Goldschmid, 1976, DeVries, 1974; Keating, 1975; Weiss, O'Neill and O'Neill, 1975). Some authors even suggested that a measure of intelligence may be a "cheaper and more reliable proxy measure" (Nagy and Griffiths, 1982, p. 535) than a test designed to measure cognitive development. Guilford (quoted in Taba, 1962) contended that reasoning is highly related to intelligence but that intelligence tests, especially group intelligence tests, touch on ability only slightly.

DeVries (1974) compared IQ tests to Piagetian tasks which she distinguished as "derived from (and have contributed to) a research-based theory of intelligence" (p. 747). DeVries summarized previous research findings bearing on the relationship between psychometric and Piagetian intelligence and categorized the research findings into those which showed low and moderate correlations. She concluded that the general picture presented by the findings she reviewed suggests some degree of overlap and some degree of non-overlap of psychometric and Piagetian measures of intelligence. The research conducted by DeVries generally agreed with prior factor-analytic studies of performance on

Piagetian, IQ, and achievement tests. She concluded that Piagetian tasks appear to measure different intelligence and different achievement than do psychometric tests. The study by Keating (1975) compared DeVries' findings, and Keating chose to reinterpret the DeVries results and concluded that "brightness" as psychometrically defined implies precocity in cognitive developmental for young adolescents (fifth- and seventh-graders).

Cloutier and Goldschmid (1976) investigated the relationship between the attainment of a formal operational concept (proportion) and 22 personal characteristics, including a general ability factor as measured by Raven's Standard Progressive Matrices. Intelligence significantly correlated with the concept of proportion, as expected by their examination of the results of several previous research studies. However, Cloutier and Goldschmid also listed a number of studies in which it was found that Piagetian measures involve abilities separate from those assessed by standard measures of intelligence.

Nagy and Griffiths (1982) used several studies involving IQ to support their argument that global measurement of developmental level is not tapping a unique variable. Suggested as "cheaper and more reliable proxy measures" (p. 535) which they suggested as linked to developmental level were measures of intelligence, field depencence-independence, and scholastic aptitude. Nagy and

Griffith cited evidence from several sources (1975 to 1980) to support the use of such measures.

## The Short Form Test of Academic Aptitude As a Measure of IQ

The Short Form Test of Academic Aptitude (SFTAA) is a series of mental ability tests for use by school children in grades 1.5 to 12. The SFTAA includes four subtests which measure vocabulary development, logical reasoning, education of quantitative relations, and meaningful memory. The SFTAA is derived from the California Test of Mental Maturity (CTMM) series. Items for each subtest of the SFTAA were obtained by selection and revision of the best multiple-choice items from previous editions of the CTMM series, and by development of additional items by the staff of the CTB/McGraw-Hill Test Development Department. The effectiveness of each item was determined by item analysis of data obtained through tryout testing.

The SFTAA was standardized by administration of the test to a national sample of 197,912 students Grades 1 through 12. Normative data for the SFTAA were based on grade groups and on chronological age groups. Instead of ratio IQ, the SFTAA uses a deviation IQ which is obtained from a normalized distribution of scores for each age group. This procedure assigns an IQ of 100 to the average raw score at each age group. Mental ages are derived by first ascertaining the average raw score for each chronological age group, and then assigning that chronological age as the mental age for the particular raw score. The test booklet states that "the IQ and age percentile rank, ... indicate the relative 'brightness' of the student. They indicate the general level of performance that may be expected in school work" (Short Form Test of Academic Aptitude, 1970, p. 30). Regarding the use of SFTAA scores, "The SFTAA is intended for use in the schools. It does not claim to measure all aspects of mental ability. Emphasis is placed on those intellectual functions of a relativly abstract nature which are important for success in an educational program. These include facility in dealing with verbal and non-verbal concepts and in comprehending relationships among ideas presented in various forms." (p 31)

The rationale behind the development of the SFTAA is that performance of students on a test of mental ability is the result of many factors.

> Innate ability cannot be measured directly, but must be inferred from observation of overt behaviors which are functions of these innate characteristics. The level of test performance becomes dependent upon opportunities which students have had to develop their abilities through experience. In general, the SFTAA elicits responses which have been developed through various channels open to all members of our culture, rather than reflecting only those which are functions of formal school training. (Short Form Test of Academic Aptitude, 1970, p. 6)

### Hypothesized Relationship Regarding IQ As an Independent Variable

On the basis of the preceding literature, it was hypothesized for the present research that higher IQ scores, as measured by the Short Form Test of Academic Aptitude, would be strongly correlated with higher ability in scientific reasoning as indicated by Figure 2.6.

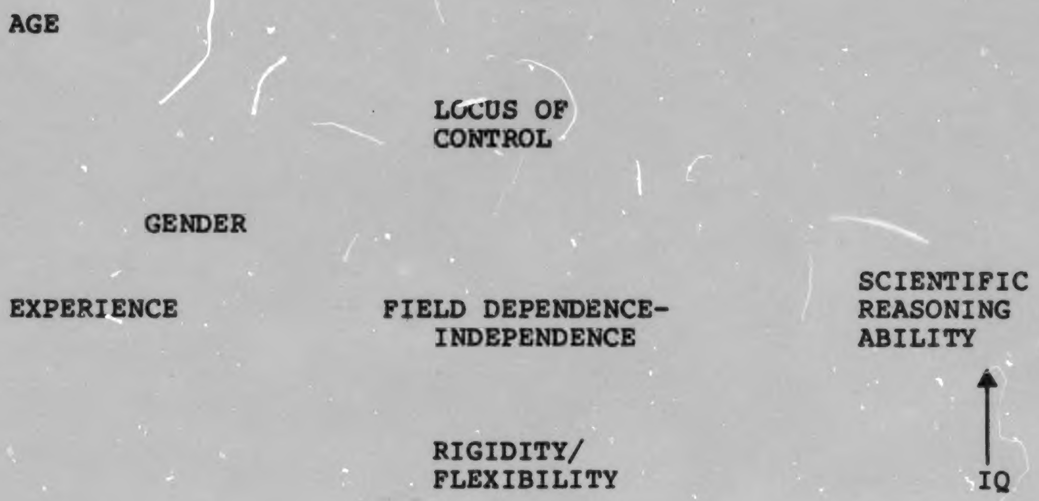

AGE
LOCUS OF CONTROL
GENDER
EXPERIENCE
FIELD DEPENDENCE-INDEPENDENCE
SCIENTIFIC REASONING ABILITY
RIGIDITY/FLEXIBILITY
IQ

Fig. 2-6 A causal model for scientific reasoning ability highlighting the proposed relationships between IQ (as the independent variable) and scientific reasoning ability.

## G. Gender

### Theoretical Considerations

The existing literature on sex-related differences in cognitive functioning at adolescence has been reviewed extensively by three sets of authors: Maccoby and Jacklin (1974), Petersen and Wittig (1979), and Archer and Lloyd (1982). The text by Maccoby and Jacklin is consistently quoted in current research studies dealing with intellectual performance and/or social behaviors that are thought to be differentiated by sex. Petersen and Wittig (in Sugar, 1979) focused primarily on female adolescent cognition; and the Archer and Lloyd text updated and supplemented the original review by Maccoby and Jacklin. All three sources cited conclusive evidence which supports the existence of gender differences in some areas of cognitive functioning; but also acknowledged that differences between sexes are not as widespread as "commonsense ideas" (Archer and Lloyd, 1982) would suppose.

> A number of the physical differences between the sexes are obvious and universal. The psychological differences are not. The folklore that has grown up about them is often vague and inconsistent. We believe there is a great deal of myth in the popular views about sex differences. There is also some substance. (Maccoby and Jacklin, 1974, p. 3)

> Although it is no longer believed that men are intellectually superior to women, it is still widely held that the two sexes think differently and have a natural bent for different intellectual activities. The preponderance of boys and men studying pure science, mathematics, engineering and architecture, and the concentration of girls and women in biology, the arts and language studies, support this view. Not only

> are sciences and engineering seen as the special domain of men, but they are viewed as more complex and difficult. Boys and girls have different skills, and those of males are superior. Old ideas do not die easily. (Archer and Lloyd, 1982, pp. 10-11)

As well, evidence is cited that indicates the emergence of sex-related differences in cognitive functioning early in adolescence, with boys becoming more proficient in mathematics and spatial skills and girls becoming somewhat more proficient in verbal skills. Petersen and Wittig presented a model based upon existing evidence to explore the gender differences occurring at adolescence and throughout adulthood in cognitive functioning: "Most likely these differences emerge as a result of interactive influences from brain organization and endocrine influences, as well as socialization and educational experiences" (p. 56). They also reported that there has been no research to integrate the various aspects; however,

> We favor an interactionist approach rather than a solely biological or sociocultural one. If the sex-related differences were strictly biological, then the differences would be more dramatic than they are. In fact, there is substantial overlap in the performance of males and females, far greater than the biological similarity of the sexes. .... Furthermore, the evidence for the differential socialization of males and femalew is clear. In addition, other recent research has begun to document how differential practices in the classroom lead to differential performance on the part of boys and girls. (Petersen and Wittig, 1979, p. 56)

The preceding quote by Petersen and Wittig introduces the discussions which follow concerning the relationships of gender to locus of control, the "social" variable of this research; of gender to experience, and of gender to field dependence-independence.

## Gender and Locus of Control

A study by Feather (1967) examined a number of personality correlates with external locus of control. Also of interest in this study were the possible sex differences in the rO]elationship of locus of control to these variables. Results of the study by Feather indicated sex differences in some instances, including a finding that females at late adolescence were more dependent and external in their locus of control than the more independent, internal males. Their results also showed that particular relationships of correlates with locus of control were significantly different for the female subgroup as compared to the male subgroup. Crandall and Lacey (1972) also included an examination of sex differences when they conducted a study hypothesizing that field dependence-independence might account for superior academic performance of children who exhibit internal locus of control. Results of this study indicated that locus of control, as measured by the Intellectual Achievement Responsibility Questionnaire, and field dependence-independence, as measured by the Embedded Figures Test, were positively correlated for both sexes. When the effects of age and IQ were partialled out, however, the significance of the field independence-internal locus of control relationship remained high for females but was reduced for males. These authors concluded that "The second-order partials with age as well as IQ removed confirm the fact that internal perceptions are able to account for girls' EFT performance over and above that provided by the control variables" (Crandall and Lacey, 1972, p. 1131). These authors then discussed the possible reasons for the observed differences, one being that males had been offered more opportunity than females to develop visual perception skills. This viewpoint has also been expressed by Kahle (1983) and others concerned with the differential effects of gender on overall science achievement.

### Gender and Experience

In a discussion regarding sex-related differences in mathematical skills, particularly in "higher" mathematics (i.e., algebra, geometry, etc.), Maccoby and Jacklin noted that the observed differences in performance on tests occur near the beginning of adolescence. Fennema and Sherman (1977) have demonstrated that some part of this result was due to differential course-taking on the part of males versus females, which again begins at adolescence. An argument could be presented that course-taking is influenced by some underlying ability, but it has also been shown that girls perform as well as boys in mathematics prior to the time when they decide to stop taking these courses. Fennema and Sherman also reported that girls appear to see mathematics as a male domain and not relevant for their own futures. Archer and Lloyd suggested that disinterest in mathematics may be due to the lack of female role models and choices for girls of careers involving the use of mathematics.

As mentioned in the section on experience, gender-related differences in experience are indeed a fact, beginning at the stage of adolescence. Sherman (1967) listed a number of activities as "differential practices," which included coursework as well as pastimes. Jane Butler Kahle in the AETS Outstanding Paper for 1983 examined a number of factors which she identified as contributing to the dearth of girls and women in science courses and careers. Kahle stated that the effect of sex/role stereotyping of physical science courses and careers as masculine deters the entrance and retention of adolescent girls, which thus means that girls have fewer experiential opportunities in those types of activities which were identified in the present study as affecting the development of scientific reasoning ability. Although experience was not the only factor mentioned in Kahle's paper, it was a major concern in terms of coursework in secondary school and extra-curricular experiences.

## Gender and Field Dependence-Independence

Because of the difficulties with the definition of intelligence, many investigators of human cognition have focused on separate cognitive abilities which contribute to overall intellectual capacity. Three specific abilities have consistently shown sex-related differences (see Archer and Lloyd, 1982; Maccoby and Jacklin, 1974; Petersen and Wittig, 1979): mathematical ability, spatial ability, and verbal ability. Males, on the average, scored higher than females on tests of spatial and mathematical ability. Females, although not as consistently as the males, scored somewhat higher on tests of verbal ability. As the cognitive style construct of field dependence-independence is included as a major portion of spatial ability, and the relationship between field dependence-independence and scientific reasoning has already been discussed, the following discussion applies to research which indicates a sex-related difference in aptitude for scientific reasoning.

Studies showing sex differences in field dependence-independence have been frequently replicated and it is generally well accepted that boys show higher scores in field independence than girls (Feather, 1967; Maccoby and Jacklin, 1974; Petersen and Wittig, 1979). Treagust (1980) suggested that a "genetic epistemological explanation" rather than a personal-historical explanation such as the one provided by Sherman (1967) accounts for the consistency of gender differences on spatial tasks in adolescents and the lack of gender differences in elementary school subjects.

> It is possible that the apparently slower development in spatial conceptualization by females is a contributing factor to their reported lower attainment of skills than that of males in handling science information at the senior high school level and in later years.(Treagust, 1980, p. 95)

Inhelder (as summarized by Sherman, 1967) pointed out that while young boys and girls of the same age do not show a difference in logical functioning, they do show a difference in formation of spatial representation, that is, the transformation and development of geometric solids. Inhelder suggested that this might serve as a preadaptation or prerequisite for later development. "A slight difference in young children might thus take on greater importance with age and be increased by differential experiences" (Sherman, 1967, p. 296).

Another viewpoint concerning the differences in spatial abilities was expressed by Kahle (1983), who explained the difference in spatial abilities by saying that girls have fewer opportunities to develop spatial visualization skills than boys do, and this she relates to science achievement. In addition, Fennema and Sherman (1977) provided evidence which demonstrates the dependence of the sex differences in spatial ability upon the number of mathematics courses taken.

Basically, then, there appeared to be both a theoretical and experimental base to support a physiologic and an experiential explanation for the observed sex-related differences in spatial abilities. In the present research both relationships were hypothesized: a direct relationship between gender and field dependence-independence, and a direct relationship between gender and experiences which contribute to the development of field independence.

## Hypothesized Relationships Concerning Gender As An Independent Variable

This research hypothesizes the following relationships concerning gender with these variables: that being female will be negatively correlated with internal locus of control; that being male will be positively correlated with level of experience; that being male will be positively correlated with field independence. Figure 2.7 indicates the hypothesized relationships among these variables.

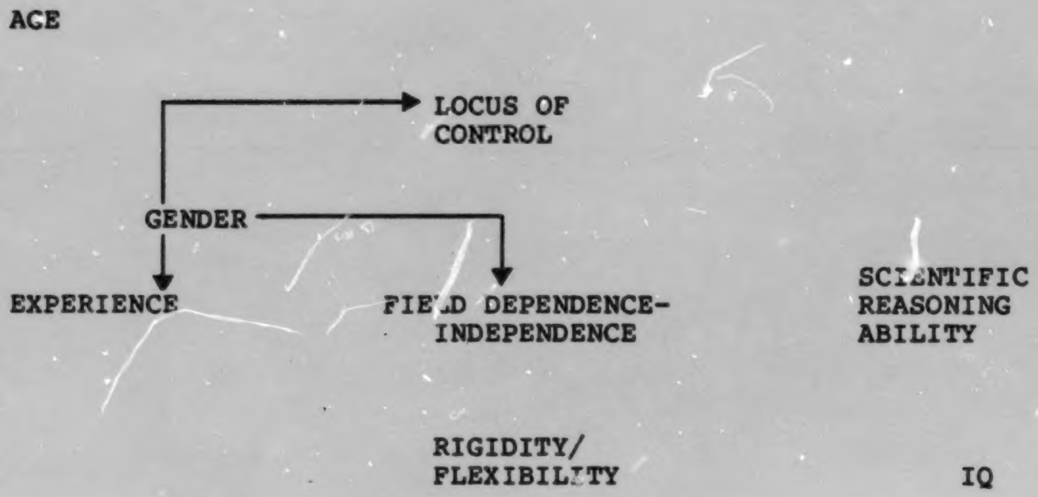

ACE
LOCUS OF CONTROL
GENDER
EXPERIENCE
FIELD DEPENDENCE-INDEPENDENCE
SCIENTIFIC REASONING ABILITY
RIGIDITY/ FLEXIBILITY
IQ

Fig. 2-7 A causal model for scientific reasoning ability highlighting the proposed relationships between gender (as the independent variable) and the variables of locus of control, experience, and field dependence-independence.

## Section III. Results of the Pilot Project for This Study

The following instruments were administered in the spring of 1983 to 120 seventh graders on an interdisciplinary team at a middle school and 65 eleventh graders in a General Humanities course at a high school in an upper middle class suburb of Columbus, Ohio: Concealed Figures Test (CFT); Breskin Rigidity Test (BRT); Gough-Sanford Rigidity Scale (GSR); Crandall Intellectual Achievement Responsibility Questionnaire (IAR); the Lawson Test of Formal Operations (SRT; Scientific Reasoning Test); and a background sheet which included self-report data on age and gender. The most recent Short Form Test of Academic Aptitude score was recorded from the student's permanent record as a measure of IQ. The Cognitive and Recreational Activity Scale (CRAS) was developed in the summer of 1983 and piloted in the fall of 1983; scores from the CRAS were therefore not available for the statistical analyses of the other data collected in the spring of 1983.

### Reliabilities of Instruments

Reliabilities for each of the instruments piloted in this study are presented in Table 2-1. All instruments were tested for reliability using Subprogram Reliability in the SPSS Update (Hull and Nie, 1979). The reliability analysis ALPHA was selected to compute Cronbach's alpha, or in the case where dichotomous data were analyzed, the KR-20 reliability coefficient. As there were difficulties with missing data on the timed Concealed Figures Test, the reliability for that instrument was calculated on the first 45 items of the test. As indicated in Table 2-1, the reliability for the GSR was 0.58. On the basis of this low value, data from the GSR were eliminated from subsequent analysis.

## Results of the Pilot Study

Summary statistics for the variables considered in the pilot study are presented for the entire wroup of 180 students in Table 2-1. A correlation matrix of all variables considered in the pilot project is presented in Table 2-2. Results of the regression of scientific reasoning ability with independent variables for all students as well as for seventh grade and eleventh grade subgroups are presented in Table 2-3. All computations were performed using programs with Statistical Package for the Social Sciences (Nie, Hall, Jenkins, Steinbrenner, and Bent, 1975). All variables listed in Table 2-1 except the CRAS were subjected wo the analyses performed in the pilot study.

## TABLE 2-1

## RELIABILITIES, MEANS, STANDARD DEVIATIONS, AND RANGES FOR PILOT PROJECT VARIABLES

| VARIABLE OR CONSTRUCT INSTRUMENT | RELIABILITY | MEAN (S.D.) | RANGE |
|---|---|---|---|
| **Experience** | | | |
| CRAS (Cognitive and Recreational Activity Scale) | 0.86 | | |
| **Social Transmission** | | | |
| IAR (Intellectual Achievement Responsibility Questionnaire | 0.68 | 21.7<br>( 6.2) | 0 - 32 |
| IAR+ Subscale | | 14.2<br>( 1.4) | 10 - 17 |
| IAR- Subscale | | 14.1<br>( 2.0) | 10 - 17 |
| **Maturation** (Age) | | 14.4<br>( 2.0) | 12 - 18 |
| **Aptitude** (Field Dependence-Independence) | | | |
| CFT (Concealed Figures Test) | 0.98 | 53.2<br>(23.6) | -16 - 126 |
| **Equilibration** (Rigidity/Flexibility) | | | |
| BRT (Breskin's Rigidity Test) | 0.81 | 6.4<br>( 2.4) | 0 - 10 |
| GSR (Gough-Sanford Rigidity Scale) | 0.58 | 10.5<br>( 3.6) | 0 - 22 |
| **IQ** | | | |
| SFTAA | | 113.0<br>(12.4) | 78 - 148 |
| **Gender** (1=male; 2=female) | | 1.5<br>( 0.5) | |
| **Scientific Reasoning Ability** | | | |
| SRT (Test of Formal Operations) | 0.85 | 8.0<br>( 4.1) | 0 - 15 |

## TABLE 2-2

## CORRELATION MATRIX OF ALL VARIABLES CONSIDERED IN THE PILOT STUDY

| | AGE | SEX | IQ | BRT | IAR | IAR+ | IAR- | CFT |
|---|---|---|---|---|---|---|---|---|
| Sex | .08 | | | | | | | |
| IQ | $-.19^{+}$ | $-.14^{*}$ | | | | | | |
| BRT | $-.31^{+}$ | .22 | .16 | | | | | |
| IAR | .11 | $.21^{+}$ | .01 | $.13^{*}$ | | | | |
| IAR+ | .05 | $.24^{+}$ | -.10 | .21 | $.79^{+}$ | | | |
| IAR- | .10 | .27+ | -.04 | .01 | $.85^{+}$ | $.45^{+}$ | | |
| CFT | $.18^{+}$ | .06 | $.30^{+}$ | $-.15^{*}$ | .06 | .12 | .06 | |
| SRT | $.49^{*}$ | -.09 | $.39^{+}$ | $-.26^{+}$ | .05 | -.03 | .04 | $.44^{+}$ |

Sex: 1=male; 2=female
BRT: high score = high flexibility
IAR: high score = internal locus of control
IAR+: high score = internal positive locus of control
IAR-: high score = internal negative locus of control
CFT: high score = field independence
SRT: high score = high scientific reasoning ability

$^{*}p <= 0.05$
$^{+}p <= 0.01$

## TABLE 2-3

### STATISTICS FOR REGRESSIONS OF LOCUS OF CONTROL, AGE, FIELD DEPENDENCE-INDEPENDENCE, RIGIDITY/FLEXIBILITY, IQ, AND GENDER ON SCIENTIFIC REASONING FOR STUDENTS PARTICIPATING IN THE PILOT STUDY

Variables in the Equation for All Students (n = 127)

| | B | Beta | R | $R^2$ | $R^2$ Chg. | $F^*$ |
|---|---|---|---|---|---|---|
| Age | 1.134 | 0.537 | 0.483 | 0.233 | 0.233 | 62.84 |
| IQ | 0.153 | 0.429 | 0.679 | 0.461 | 0.228 | 38.86 |
| FDI | 0.331 | 0.191 | 0.702 | 0.493 | 0.165 | 7.76 |

*F (.05, df 1,123) = 3.92

Variables in the Equation for 7th Grade Students (n = 83)

| | B | Beta | R | $R^2$ | $R^2$ Chg. | $F^*$ |
|---|---|---|---|---|---|---|
| IQ | 0.160 | 0.462 | 0.471 | 0.222 | 0.222 | 22.57 |
| Age | 2.657 | 0.289 | 0.565 | 0.320 | 0.100 | 9.78 |
| IAR+ | -0.327 | -0.229 | 0.598 | 0.357 | 0.037 | 6.57 |
| CFT | 0.000 | 0.229 | 0.636 | 0.405 | 0.048 | 6.33 |

*F (.05, df 1,79) = 3.96

Variables in the Equation for 11th Grade Students (n = 44)

| | B | Beta | R | $R^2$ | $R^2$ Chg. | $F^*$ |
|---|---|---|---|---|---|---|
| IQ | 0.132 | 0.493 | 0.584 | 0.341 | 0.341 | 13.97 |
| CFT | 0.000 | 0.238 | 0.625 | 0.390 | 0.049 | 3.25 |

*F (.05, df 1,41) = 4.08

## Discussion

The experience variable was measured by the Cognitive and Recreational Activity Scale which was developed by the author for use in the final study. A ranking sheet of items selected to represent common activities of adolescents was presented to ten secondary school educators. Means of each item were calculated from the responses of the educators, and the weights assigned to each item are the calculated means. Items with a mean below 2.00 were eliminated. The final questionnaire, which was piloted in the fall of 1983 with 28 seventh graders, had a reliability of 0.84. As this instrument was not included in the battery of instruments administered to the large numbers of students in the spring of 1983, no further analyses were possible using this instrument.

Locus of control was measured by the Crandall Intellectual Responsibility Questionnaire (IAR), which resulted in an overall reliability of 0.66. Reliabilities of subscales IAR+ and IAR- were not performed. The correlation matrix presented as Table 2-3 indicates that significant correlations of locus of control with gender and with the measure of rigidity/flexibility (BRT). The IAR+ subscale showed significant correlations with gender. As well, the multiple regression indicated that the IAR+ subscale had some predictive value for scientific reasoning ability in younger adolescents.

A preliminary discriminant analysis indicated that the IAR+ subscale was one of five discriminators which separated high- and low-ability scientific reasoning groups. Possible relationships between the IAR- subscale and other variables were not as evident as with the IAR+, although the IAR- subscale did show a significant correlation with the gender variable. The finding that being female correlated with higher values on the IAR was not concurrent with research which shows that females generally have a more external locus of control.

Age appeared in the pilot study as a strong predictor of field independence and of scientific reasoning ability; it was also the strongest discriminator between high- and low-ability groups in the discriminant analysis.

Concerning the measure of field dependence, a reliability of 0.98 was obtained when the first 45 items of the Concealed Figures Test (CFT) were used. The CFT revealed significant relationships with scientific reasoning ability and with other variables of age, IQ, and the measure of rigidity/flexibility. The regression of scientific reasoning ability (Table 2-3) further indicated predictive strength of this variable.

Significant correlations of rigidity/flexibility, as measured by Breskin's Rigidity Test (BRT), with age, locus of control (IAR), and field dependence-independence (CFT) are indicated in Table 2-2. The multiple regression summarized in Table 2-3 indicates this variable to be a strong predictor of scientific reasoning ability; as well, the BRT was chosen in the discriminant analysis as one of the first variables discriminating between high- and low-ability scientific reasoning groups. The reliability of this instrument was calculated to be 0.81.

IQ, as measured by the total score of the Short Form Test of Academic Aptitude, showed strong correlations with scientific reasoning ability (Table 2-2), and its power among variables in predicting scientific reasoning was indicated in the regressions (Table 2-3). Correlations with other variables (Table 2-2) indicate relationships with field dependence-independence (CFT) and possible confounding with age and gender. IQ was also selected in a preliminary discriminant analysis to be a strong discriminator between high- and low-ability groups of scientific reasoning.

Relationships of gender with locus of control (IAR, IAR+, IAR-) as seen in Table 2-2 indicate a positive relationship between being female and possession of internal locus of control. This relationship is contrary to the literature, and these findings are discussed further in Chapter Four of this dissertation.

The Test of Formal Operations was used as a measure of scientific reasoning ability and was administered as an intact instrument to both groups of students. A reliability of 0.86 was calculated for this instrument. Table 2-2 shows significant correlations of this variable with rigidity/flexibility (BRT), field dependence-independence (CFT), IQ, and age.

## Implications of the Pilot Study Results for the Current Research

Support for the following hypothesized relationships was obtained as a result of the pilot study for the following pairs of variables: female gender and internal locus of control; rigidity and field independence; rigidity and higher scientific reasoning ability; IQ and higher scientific reasoning ability; age and rigidity; and age and higher scientific reasoning ability. Figure 2-8 depicts these relationships as those which support the hypothesized paths indicated on the figure. On the basis of these findings, it was decided to include all variables listed in Table 2-1 except the GSR in the final study. The GSR was eliminated because of the low reliability and inappropriateness of the questions to the ages included in the study. The construct of rigidity/flexibility was used in the final study.

The results also implied that a path analytic approach was more appropriate than a regression analysis to the assessment of relationships between variables which impinge upon scientific reasoning. For this reason, multiple regression techniques were abandoned in favor of applied regression analysis in the context of path analysis.

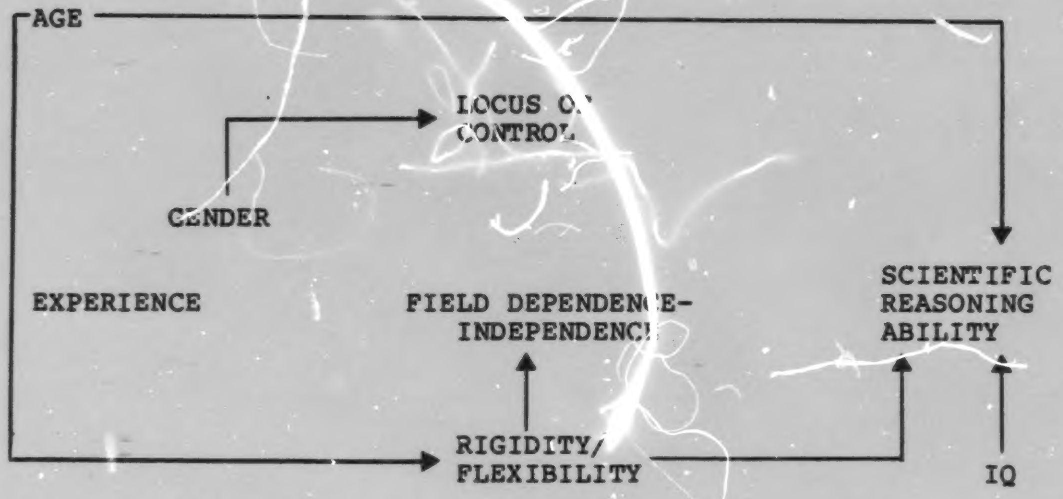

AGE
LOCUS OF CONTROL
GENDER
EXPERIENCE
FIELD DEPENDENCE-INDEPENDENCE
SCIENTIFIC REASONING ABILITY
RIGIDITY/FLEXIBILITY
IQ

Fig. 2-8. A causal model for scientific reasoning ability highlighting paths between pairs of variables which were suggested by data gathered during the pilot project. Lines between pairs of variables were drawn as a result of significant correlations between the variables (see Table 2-2). Directionality is imposed as a result of theoretical considerations and empirical research reviewed in Section II of this chapter.

## Section IV. Path Analysis

### Theory of Path Analysis

Sections I and II of this chapter described the theoretical and empirical details relevant to the examination of variables included in the present study. These sections, as well, established a foundation upon which the causal model presented in Chapter One was hypothesized regarding the relationships between the independent variables and the ultimate dependent variable, scientific reasoning ability. Path analysis was chosen as the appropriate method for testing the hypothesized directional relationships among the variables. This final section of Chapter Two outlines major characteristics of this method, as described by Asher (1976) and Pedhazur (1982), providing some aspects of the theory behind the procedures of analysis presented and discussed in detail in Chapter Three.

The method of path analysis was developed by Sewall Wright, a geneticist, to study the direct and indirect effects of variables taken as causes of variables taken as effects. Both Asher and Pedhazur pointed out that path analysis is not a method for discovering causes, but a method applied to a causal model formulated by a researcher on the basis of knowledge and theoretical considerations. A quote by Wright which appears in Pedhazur is excerpted in the following passage:

> The method of path coefficients is not intended to accomplish the impossible task of deducing causal relations from the values of correlation coefficients. It is intended to combine the quantitative information given by the correlations with such qualitative information as may be at hand on causal relations to give a quantitative interpretation. (Pedhazur, 1982, p. 580)

Asher stresses that even in situations where causal analysis techniques, such as path analysis, are difficult or even impossible, a causal approach to theorizing can be valuable as a heuristic device. "Thinking causally about a problem and constructing an arrow diagram that reflects causal processes may often facilitate the clearer statement of hypotheses and the generation of additional insights into the topic at hand" (Asher, 1976, p. 8).

### The Model

Asher warned that "the model which the researcher proposes should be constructed with substantial confidence, resulting from some theoretical or substantive reasoning about the linkages between the variables of interest" (Asher, 1976, p. 6). The model not only specifies the relationships between the independent variables and the ultimate dependent variable of interest, but also makes explicit the relationships among the prior variables. Each included linkage implicitly represents a hypothesis which is tested by an estimation of the magnitude of the relationship. Asher evaluated this kind of causal thinking as having greater promise than simply correlating independent and dependent variables in a "relatively unthinking fashion." There are, however, three limitations which should be recognized in order to infer the existence of a causal relationship between two variables, X and Y, which are listed below (Asher, 1976):

(1) There must be concomitant variation or covariation between X and Y;

(2) There must be a temporal asymmetry or time ordering between the two;

(3) Other possible causal factors must be eliminated which may be producing the observed relationships between X and Y.

Asher makes special note that the third condition asserts that for there to be a causal relationship between X and Y, the covariation between X and Y should not vanish when the effects of confounding variables (those variables causally prior to both X and Y) are removed.

### Variables in the Path Model

In a given model variables may take two general forms. They may be variables which serve only to explain or predict other elements of the model (exogenous variables), or they may be variables which both serve to predict some elements of a model while along being predicted by other elements of the model (endogenous variables). Residual variables are introduced to indicate the effect of variables not included in the model. In standard regression terms the residual is often considered as unexplained variance. This variance could normally be attributed to variance from variables not included in the model and to error variance.

### The Path Diagram

The path diagram is a useful device for displaying graphically the pattern of causal relations among a set of variables. It indicates the following information (Asher, 1976):

(1) Which variables are exogenous, that is, which are those whose variability is assumed to be determined by causes outside the causal model. No attempt is made to explain the variability of an exogenous variable or its relations with other exogenous variables.

(2) Which variables are endogenous, or those whose variation is explained by exogenous or endogenous variables in the system.

(3) Paths, which are drawn in the form of unidirectional arrows, from the variables taken as causes (independent) to the variables taken as effects (dependent).

(4) Causal flow, either unidirectional (in which case the model is called recursive) or bidirectional (where the model is called nonrecursive). In recursive models, at a given point in time, a variable cannot be both a cause and an effect of another variable.

(5) Residual variables, introduced to indicate the effect of variables not included in the model.

The arrow diagram can be converted to a system of equations that reflect the linkages of the diagram. One structural equation can be written for each endogenous variable. Asher suggested that variables be standardized, giving them a mean of zero and a standard deviation of one and also assuming that the unmeasured residual terms are also standardized. Asher also suggested that standardizing the variables makes derivations simpler and will not, in most causes, upset the generalizability of the results.

### Path Coefficients

Pedhazur (1982) simply explained a path coefficient as "the direct effect of a variable taken as a cause of a variable taken as an effect" (Pedhazur, 1982, p. 583). Each endogenous (dependent) variable in a causal model may be represented by an equation consisting of the variables upon which it is assumed to be dependent, and a term representing residuals, or variables not under consideration in the given model. For each independent variable in the equation there is a path coefficient indicating the amount of expected change in the dependent variable as a result of a unit change in the independent variable. Notation for a path coefficient is a $p$ with two subscripts, the first indicating the effect (or the dependent variable) and the second subscript indicating the cause (the independent variable). Figure 2.9 indicates the path coefficients for the variables included within the present study.

### Analysis of the Causal Model

Obtaining Path Estimates.-- Path analysis is basically concerned with estimating the magnitude of the linkages between variables and using these estimates to provide information about the underlying causal processes. The

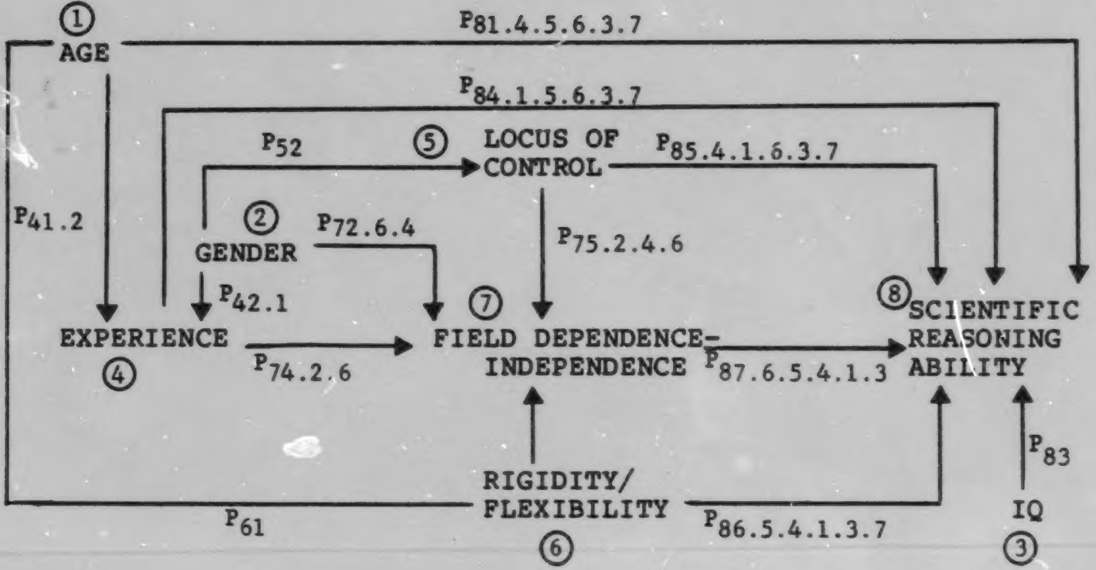

① AGE
$P_{81.4.5.6.3.7}$
$P_{84.1.5.6.3.7}$
$P_{52}$
⑤ LOCUS OF CONTROL
$P_{85.4.1.6.3.7}$
$P_{41.2}$
② GENDER
$P_{72.6.4}$
$P_{75.2.4.6}$
$P_{42.1}$
⑦ FIELD DEPENDENCE-INDEPENDENCE
⑧ SCIENTIFIC REASONING ABILITY
EXPERIENCE ④
$P_{74.2.6}$
$P_{87.6.5.4.1.3}$
$P_{83}$
RIGIDITY/ FLEXIBILITY ⑥
$P_{61}$
$P_{86.5.4.1.3.7}$
IQ ③

Fig. 2-9. A causal model displaying notations used to designate hypothesized relationships between variables which ultimately affect scientific reasoning. These notations signify the order of removal of variables in the multiple regressions performed to obtain path coefficients for each of the relationships depicted.

estimates can be obtained by a number of ways, but Asher (1976) suggested that the simplest way to obtain the path coefficients is to employ ordinary regression techniques, providing that the regression assumptions are met, particularly the requirement that the residual variable in a structural equation be uncorrelated with the explanatory variables in the equation.

The method of obtaining estimates of the main path coefficients was also one suggested by Asher: one simply regresses each endogenous variable on those variables that directly impinge upon it. Residual path coefficients are ascertained by ordinary regression analysis, as they have a direct regression interpretation. The general form of a residual path coefficient is $\sqrt{1 - R^2}$ where $R^2$ is the square of the appropriate multiple correlation coefficient. Asher notes that the $R^2$ is commonly referred to as the fraction or proportion of explained variance. Since standardized variables have a variance of one, the general expression $1 - R^2$ is simply the proportion of unexplained variance. Therefore, the residual path coefficient is simply the square root of the unexplained variance in the dependent variable in question.

Asher summarizes the process of recursive path analysis as follows:

> Recursive path analysis can be carried out within the context of ordinary regression analysis and does not require the learning of any new analysis techniques with the proviso that the issue is still open as to how to optimally treat the situation of excess equations. The real utility of path analysis comes in what one does with the path estimates once they are determined. (Asher, 1976, p. 32)

## Interpreting the Path Coefficients

This method enables one to measure the direct and indirect effects that one variable has upon another. It also enables one to decompose the correlation between any two variables into a sum of simple and compound paths with some of these compound paths being substantitively meaningful indirect effects and others perhaps not. The easiest method for decomposing correlations is to read the simple and compound paths directly from the arrow diagram using the following rules which have been attributable to Sewall Wright and which appear in Asher (1976):

(1) Any correlation between two variables can be decomposed into a sum of simple and compound paths;

(2) A compound path is equal to the product of the simple paths comprising it;

(3) No path may pass through the same variable more than once;

(4) No path may go backward on (against the direction of) an arrow after the path has gone forward on a different arrow;

(5) No path may pass through a double-headed curved arrow more than once in any single path.

Asher notes that the decomposition of the correlation is extremely important in that it yields information about the causal processes and also provides a way in which to test the adequacy of the model if some linkages have initially been omitted. If the model were specified correctly, then the empirical correlation between any two variables should be numerically equal to the sum of the simple and compound paths linking the two variables. If the equality does not hold, this suggests that the model may be improperly specified and in need of revision.

> Using correlation decomposition as a test of the model may entail substantial work; fortunately a much simpler procedure is available. If a linkage has been omitted from the model, implicitly it is said that the expected magnitude of the path coefficient is zero. Thus, the test of the model becomes whether the omitted coefficient is indeed zero, the magnitude of the omitted linkage being determined by estimating the model with the linkage under question included. (Asher, 1976, p. 34)

Asher emphasizes that path analysis is superior to ordinary regression analysis since it allows one to move beyond the estimation of direct effects, which is the basic output of regression. Rather, path analysis when used to evaluate causal models allows one to examine the observed relationships and to estimate the relative importance of alternative paths of influence. The model testing permitted by path analysis further encourages a more explicitly causal approach in the search for explanations of the phenomena under investigation.

## Summary Statement of Chapter Two

A background from the literature is presented in Sections I and II of this chapter for the establishment of a model of causation among a number of interrelated variables identified as potential determinants of scientific reasoning: experience, locus of control, age, field dependence-independence, rigidity/flexibility, IQ, and gender. Preliminary work done by this author in the examination of the relationships between variables reported in Section III presents results which led to the selection of causal modeling as the most appropriate next step in the examination of the aforementioned relationships. Information regarding path analysis procedures as used to verify causal models is presented in Section IV. This section forms a foundation from which the methodology for the present study was formulated.

# CHAPTER THREE

## METHODOLOGY

This chapter outlines the methods and procedures followed during the course of the present study. Major sections of this chapter include: details of the research design; a discussion regarding the subjects chosen for the study; details of instrumentation including the administration of instruments, a description of the instruments themselves, and preliminary instrument analyses; and finally, the statistical procedures employed to test the hypotheses proposed in the present research.

### Research Design

The study conducted was descriptive in nature, seeking to gain information regarding the hypothesized relationships between experience, locus of control, age, field dependence-independence, rigidity/flexibility, IQ, and gender and the primary dependent variable, scientific reasoning ability. Data were collected to assess the existing characteristics of secondary school subjects at two stages in adolescence and, from the data collected, attempts were then made to test a causal model of scientific reasoning ability. In this process, general correlations of variables were used to examine simple relationships between variables; a quasi-experimental post hoc two-group approach was used to examine the effect of age on several of these simple relationships; and a path analytic approach was used to examine the causal model postulated.

## Subjects

The community from which the subjects were chosen for this study is an upper middle-class, predominantly white, suburb of Columbus, Ohio. The school district which serves that community has seven elementary schools, two middle schools, and one high school. Younger adolescents used in the study were students of one seventh grade interdisciplinary teaching team. That team was responsible for team teaching 106 heterogeneously grouped students. The interdisciplinary team approach provided instruction in English, social studies, science, and mathematics. Within the team, approximately one-quarter of these students had been designated as having above-average skills in mathematics and met together as a group for one mathematics class. Otherwise, no set groupings existed for classes within the team.

The sample of the older adolescents was drawn from five high school classes. To insure a representative sample, two general chemistry classes, a general humanities class, an English composition class, and an American novel class were chosen. This sample of 92 students contained students from tenth, eleventh, and twelfth grades. Table 3-1 presents demographic data concerning these two sample populations.

## Administration Techniques

For all classes, students were tested as intact classes during regular class time. The day before actual testing, the students were presented with an oral description of the study, and they received a consent form and a letter explaining the nature of the study. Students were requested to participate in the study, and the consent form and explanatory letter were to be taken home to be signed by a parent or guardian. The day of the testing, consent forms were collected and packets which contained coded copies of answer sheets to all instruments distributed to students. Students wrote their names on the outside of these packets. They were requested to provide information regarding their age, gender, and grade in school on a demographic sheet within the folder. This sheet was also used by the researcher for recording the IQ score found in the child's permanent record. After recording IQ scores, folders with the students' names were discarded to insure student anonymity.

## TABLE 3-1

### DEMOGRAPHIC DATA REGARDING TOTAL SUBJECTS AND SUBJECTS BY AGE GROUPS

| VARIABLE | TOTAL SUBJECTS | YOUNGER AGE GROUP | OLDER AGE GROUP |
|---|---|---|---|
| Number of Subjects by Day | | | |
| - Day 1 | 198 | 106 | 92 |
| - Day 2 | 190 | 101 | 89 |
| Attrition | 8 | 5 | 3 |
| Useable Number of Subjects by Grade Level | | | |
| - Grade 7 | | 101 | |
| - Grade 10 | | | 13 |
| - Grade 11 | | | 52 |
| - Grade 12 | | | 24 |
| Age of Subjects | | | |
| Mean | 14.8 | 12.9 | 17.0 |
| Std. Dev. | 2.1 | 0.7 | 0.8 |
| Gender[1] | | | |
| Mean | 1.5 | 1.5 | 1.5 |
| Std. Dev. | 0.5 | 0.5 | 0.5 |
| IQ | | | |
| Mean | 111.5 | 112.1 | 110.8 |
| Std. Dev. | 11.3 | 11.8 | 10.7 |

---

[1] Gender is coded so that 1=male and 2=female

Except in the case of the general humanities class, which met for double class periods, two consecutive days were used for administering the instruments to the classes participating in the study. In the case of the general humanities class, testing was done all on one day, with a 10-minute break between the two 45-minute testing periods. Administration of instruments occurred during the latter half of November and the month of December of 1983. The testing schedule for all classes appears as Table 3-2.

Responses from the Scientific Reasoning Test were graded by the researcher and then marked on a computer coding sheet. These coded responses and data directly from the other instruments were entered onto magnetic tape by a commercial data transcription service. The tape containing the data was loaded into the computer at the Ohio State University for subsequent analysis. All statistical procedures conducted were done using the Statistical Package for the Social Sciences (Nie, Hull, Jenkins, Steinbrenner, and Bent, 1975). These procedures included the generation of frequency distributions for items and instrument scores, the calculation of reliabilities of instruments, and both correlational and regression analyses.

## TABLE 3-2

### TESTING SCHEDULE FOR MIDDLE SCHOOL AND HIGH SCHOOL CLASSES PARTICIPATING IN THE STUDY

| | EXPLANATION OF STUDY | TESTING DAY ONE | TESTING DAY TWO |
|---|---|---|---|
| HIGH SCHOOL CLASSES | | | |
| English composition | 11-28-83 | 11-29-83 | 11-30-83 |
| American novel | 11-28-83 | 11-29-83 | 11-30-83 |
| General chemistry | 12-07-83 | 12-08-83 | 12-09-83 |
| General humanities | 12-12-83 | 12-13-83 | 12-13-83 |
| MIDDLE SCHOOL CLASSES | 12-02-83 | 12-05-83 | 12-06-83 |

## Instrumentation

### Instruments

The following instruments were administered to the middle school and high school classes participating in the study:

Scientific Reasoning Test (SRT).-- Thirteen items from the Lawson Test of Formal Operations (Lawson, 1978), a group demonstration test consisting of fifteen items, were used to assess the ultimate dependent variable, scientific reasoning ability. Replacing items 1 and 2 from the Lawson test were two questions developed by the author to determine the ability to use propositional logic. Students were required in this test to choose an answer from a set of four choices to a question dealing with a demonstration performed by the teacher. The students also wrote a justification for their choice in their own words following the choice of the response. Each item of the test was graded by the researcher on the basis of whether the correct response was supported by an appropriate justification. Students received one point for each correct item. Low scores (1-5) on the fifteen items in this test were used as the criterion for demonstrating low scientific reasoning ability; high scores (11-15) indicated high ability in scientific reasoning. Appendix E is a copy of the questions and answer sheets for this test.

Cognitive and Recreational Activity Scale (CRAS).--This instrument was developed by the author to examine the depth and variability of experience of students in concrete manipulation and spatial visualization. The instrument, in its final form, contained 22 items, which were designated by a panel of judges as contributing to the development of reasoning abilities in adolescents. Individuals were requested to respond to each item as to how frequently they participated in the activity listed. Responses were recorded as "seldom or never," "occasionally," or "often," which received a score value of 1, 2, or 3, respectively. In the development of this instrument, referees were asked to rank with a value of 1, 2, or 3 (with 1 being low and 3 being high in contribution) each of the activities as to the effect that each had in contributing to the development of reasoning in adolescent. Weights for each item were then determined by calculating the mean of the ranks of that item. The score of any item was the computed scorebased upon student response to the item multiplied by the assigned referees' weight. The total test score was calculated by adding the scores for each item. Appendix B is a copy of this instrument.

Crandall Intellectual Achievement Responsibility Questionnaire (IAR).-- A locus of control measurement was taken to determine the overall extent to which an individuals perceived their own control over experiences occurring within the environment. The Crandall Intellectual Achievement Responsibility Questionnaire (Crandall, Katkovsky, and Preston, 1962) was used. This instrument consisted of 34 forced-choice items which indicate overall perceived internal control. Two subscales were identified from the items constructed to indicate internal control: the internal-positive subscale and the internal-negative subscale, each containing 17 items. These subscales indicate the degree to which an internal individual assumes credit for positive events and negative events, respectively. This test was designed for use by school children and items were constructed to apply to the school setting only. As this test relies heavily on reading comprehension, in the present study, reading comprehension percentile scores of students were correlated with the IAR to give some indication of validity of the instrument. For the younger adolescent group, the correlation of reading score with IAR was 0.14 ($n$=82; $p < 0.10$); for the older adolescent group, the correlation was 0.16($n$=76; $p < 0.08$). Both correlations indicated that the test total was not based primarily on reading ability of students involved in the study. For scoring this test, there were 16 reversed items which were accommodated as a portion of the analysis procedures. This instrument appears in Appendix D.

Concealed Figures Test (CFT).-- A measurement of field dependence-independence was used to determine the aptitude variable in the present study; i.e., that is, the cognitive style ability in perceiving figures when embedded within another frame of reference. The Concealed Figures Test, Form A (Thurstone and Jeffrey, 1965) is a timed, 10-minute group test consisting of a total of 196 items. Students were instructed to mark on an answer sheet whether a simple figure was present within a more complex figure. This instrument was also scored by computer.

Breskin Rigidity Test (BRT).-- A measure of perceptual rigidity was used to determine the extent to which an individual prefers closure in perceiving experience. Breskin's Rigidity Test (Breskin, 1968) is a non-verbal test consisting of 15 items each of which contains a "closed" and an "open" figure, differing with respect to the Gestaltist laws of Praegnanz. Students were requested to choose which of the visual stimuli they prefer. Six items on this instrument were reversed, and total scores for this instrument reflect an accommodation of those reversals. This instrument appears in Appendix C.

Background Data Sheet.-- A background data sheet was included within the folder of instruments in which gender, date of birth, class, teacher, and grade level were reported. This sheet was also used by the researcher to record reading scores and total IQ scores from the students' permanent record files. Folders marked with student's names were discarded upon completion of this recording process to insure subject anonymity.

## Instrument Analysis

Means, standard deviations, ranges, and reliabilities for instruments and background variables examined in the present study are presented in Table 3-3. These statistics were calculated using the SPSS Frequencies and Breakdown Subprograms (Nie et al., 1979). Table 3-4 presents statistics for students broken down by younger and older adolescent populations.

## TABLE 3-3

## RELIABILITIES, MEANS, STANDARD DEVIATIONS, AND RANGES FOR INSTRUMENTS AND VARIABLES FOR ALL SUBJECTS

| VARIABLE OR INSTRUMENT | RELIABILITY | MEAN | S.D. | RANGE |
|---|---|---|---|---|
| Experience (CRAS) | 0.65 | 53.4 | 1.1 | 30 - 88 |
| Locus of Control (IAR) | 0.65 | 22.3 | 7.1 | 0 - 32 |
| Age | | 14.8 | 2.1 | 11.9 - 19.0 |
| Field Dependence-Independence (CFT) | 0.81 | 40.7 | 23.8 | -17 - 119 |
| Rigidity/Flexibility (BRT) | 0.75 | 5.7 | 2.2 | 0 - 10 |
| IQ (SFTAA) | | 111.0 | 11.3 | 86 - 147 |
| Scientific Reasoning Ability (SRT) | 0.82 | 6.9 | 3.8 | 0 - 15 |

## TABLE 3-4

## RELIABILITIES, MEANS, AND STANDARD DEVIATIONS FOR INSTRUMENTS AND VARIABLES BY AGE GROUP

| VARIABLE OR INSTRUMENT | GROUP[a] | RELIABILITY | MEAN | S.D. |
|---|---|---|---|---|
| Experience | 1 | 0.63 | 66.71** | 10.59 |
| (CRAS) | 2 | 0.65 | 61.13** | 9.57 |
| Locus of | 1 | 0.64 | 21.12* | 7.57 |
| Control (IAR) | 2 | 0.68 | 23.62* | 6.26 |
| Age | 1 | | 12.91** | 0.74 |
| | 2 | | 16.96** | 0.84 |
| Field Dependence- | 1 | 0.76 | 31.18** | 19.60 |
| Independence (CFT) | 2 | 0.82 | 51.60** | 23.64 |
| Rigidity/ | 1 | 0.67 | 6.35** | 1.91 |
| Flexibility (BRT) | 2 | 0.77 | 4.97** | 2.31 |
| IQ | 1 | | 112.09 | 11.80 |
| (SFTAA) | 2 | | 110.77 | 10.70 |
| Gender | 1 | | 1.5 | 0.50 |
| (1=male;2=female) | 2 | | 1.5 | 0.50 |
| Scientific Reasoning Ability | 1 | 0.77 | 4.75** | 2.94 |
| (SRT) | 2 | 0.69 | 9.47** | 3.05 |

[a] Group 1 = younger adolescent group (n=101)
2 = older adolescent group (n=89)

*p < .01 F-test of significance in the Analysis of Variance for between-group differences

**p < .001 F-test of significance in the Analysis of Variance for between-group differences

All instruments were tested for reliability using Subprogram RELIABILITY, as described in the SPSS Update (Hull and Nie, 1979). The reliability analysis ALPHA was selected to compute Cronbach's alpha, which in the case where dichotomous data were analyzed, reduces to the KR-20 reliability coefficient.

## Statistical Analyses

Raw data from all instruments were transferred from answer or coding sheets to magnetic tape and subsequently placed on the computer at Ohio State University. All analyses conducted were accomplished using appropriate subprograms in the Statistical Package for the Social Sciences (SPSS; Nie et al., 1975).

### Preliminary Analyses

Preliminary analyses consisting of descriptive statistics and instrument reliabilities are discussed in the previous section and reported in Table 3-3 and Table 3-4.

### Correlational Analyses: Hypothesis I

The correlational analyses associated with Hypothesis I were conducted using the SPSS Subprogram PEARSON CORR. To adjust for the possibility of a Type I error encountered when multiple correlations are conducted using data from one set of subjects, procedures based on simple probability theory were used. These procedures resulted in the readjustment of the level of significance at which a correlation would be accepted as significant to 0.004.

### Comparison of Correlation Coefficients: Hypothesis II

Differences between coefficients of correlation for pairs of variables calculated for the younger and older adolescent groups were compared using Fisher's Z test. In this test, the correlation coefficients being examined were transformed to Z-scores. The differences between pairs of Z-scores were then divided by appropriate standard errors and compared with tabled values to determine if the Z test yielded significant results (Guilford and Fruchter, 1978).

### Regression Analyses: Hypothesis III

Regression analyses associated with Hypothesis III were performed using the SPSS Program REGRESSION to obtain estimates of coefficients for paths as proposed by the hypothesized causal model. Each endogenous variable in the model was regressed by the variables which directly impinged upon it. The path coefficient derived in this manner can be seen as the standardized regression coefficient, Beta, obtained for the variable for which the path originates when it is entered as the last parameter in a multiple regression incorporating all variables which impinged upon the focus of the converging paths. Residual path coefficients were ascertained by using the $R^2$ calculated from the ordinary regression analysis involving that endogenous variables with those impinging upon it. These calculations took the general form $\sqrt{1 - R^2}$. Once the path coefficients were obtained, paths were eliminated if the coefficient was not statistically significant. Path coefficients for paths remaining within the model were then recalculated.

## Factors Jeopardizing Validity of the Study

Campbell and Stanley (1973) list twelve factors jeopardizing the validity of various experimental designs. Although the present study is descriptive and not experimental, comments made below apply to those factors which have been identified that also may influence the validity of a descriptive study. The concerns of internal validity examine factors present which, if not controlled for, might produce effects confounded with the results of the study. External validity deals with the question of generalizability, and will not be addressed in detail in the present discussion. Limitations of the present study are such that the results are not generalizable past the sample population. Subsequent studies will be necessary to address the generalizability of the model proposed herein. The discussion which follows, then, applies to those factors which may influence the internal validity of the present study.

## Concerns of Internal Validity

*History*.-- This factor addresses the specific events in addition to the treatments in an experimental study which may alter the outcome of the study. As this study was not experimental, this factor was not considered a threat to the validity of the study.

*Maturation*.-- In some instances, there may be processes occurring within individuals as a function of the passage of time during the study which may influence the outcome of a study. In the present study, this factor was not a threat because of the point in time nature of this study. No treatment occurred during which a subject might have undergone maturational changes.

*Testing*.-- The effects of taking tests, particularly if the setting is intense, could have an adverse effect on some students. Cooke and Campbell (1979) refer to such effects as "resentful and demoralizing" effects. The instruments chosen for inclusion within the present study offered a variety of formats and most often were short-answer in nature with very little reading. The formats for the instruments used in the study were as follows: the BRT and CFT consisted of visual stimuli from which students made choices regarding which of a pair of figures they preferred (BRT) or whether a figure contained a simpler figure within it (CFT); the SRT incorporated teacher demonstrations in which questions were asked verbally and presented in written form on the answer sheet; the CRAS was check-response; and the IAR consisted of reading forced-choice statements. Testing fatigue, particularly in the younger adolescent sample, could have ensued from responding to the latter test, which consisted of 34 items which contained two statements each. Generally, the two class periods were adequate for students to respond to instruments without much apparent pressure; and it is the opinion of this researcher that testing effects did not interfere with the results of the present study.

Instrumentation.-- Regarding the instruments used in the present study, the strengths and limitations to each instrument and how these factors might affect the overall validity of the study are discussed below:

(1) CRAS - This test was developed for use in the present study along similar lines to a test developed and described by DeCarlo (1974). Activities used in the final scale were limited to a list which was originally developed by the present author and then identified by experts in adolescent thinking as contributing to the acquisition of reasoning skills. Limitations may have occurred in terms of the choice of original activities to be included in the rating sheet, as well as the item rankings of the experts.

(2) IAR - The IAR is a lengthy test which requires considerable reading. Particularly with the younger adolescent population, reading ability and/or fatigue could

be a factor affecting the validity of the instrument. However, the instrument was developed for use with children spanning the ages of the present study, and the IAR has been used extensively in studies dealing with the locus of control of school children. In dealing with the problem concerning variability which may result from children of two reading abilities (due to differences in age) taking the same test, IAR scores from both age groups were correlated with a California Achievement Test reading comprehension score recorded in the students' permanent records. The correlations of 0.14 ($\underline{n}$=82; $p < 0.10$) and 0.16 ($\underline{n}$=76; $p < 0.08$) obtained for younger and older adolescent age groups, respectively, with the dependent variable confirmed that differences in reading ability did not significantly contribute to differences in measurement of the locus of control construct in the two age groups.

(3) CFT - There appeared to be no threats to the validity of the study with the use of this instrument. Instructions for taking the test were verbal; the first two questions were used as examples to assure understanding by students in how the test was to be taken. The CFT is a popular test for measuring the construct of field dependence-independence and has been used with adolescent populations in a number of studies described in Chapter Two.

(4) BRT - This instrument has been used in a number of studies dealing with the rigidity of school children (e.g.,

Breskin, 1969; Breskin and Rich, 1971). The rationale which Breskin provides for the development of a non-verbal test to measure the construct of rigidity convinced the researcher in the present study that the instrument was appropriate in measuring this construct. This instrument is very simple in format and takes only a few minutes to administer, definite benefits in dealing with the younger adolescents participating in the study.

(5) SRT - Thirteen of the 15 items of this test have been administered to hundreds of school children throughout the country as part of the Test of Formal Operations. Its appropriateness for the ages of the subjects in the present study is well substantiated. The rationale for the replacement of the first two items on the Lawson test by two items developed by the author is addressed in Chapter Two. There is no reason for this author to believe that the replaced items pose a threat to the validity of the study, as they were developed to measure an aspect of scientific reasoning ability not addressed in the Lawson test, i.e., the ability to use propositional logic. The appropriateness of using a substantial number of the Lawson items in measuring scientific reasoning ability is addressed in detail in Section I of Chapter Two. That discussion provides a rationale for the use of these items in the measurement of the ultimate dependent variable in the present study.

(6) SFTAA (IQ) - The details of the development of this test and its use as a national standard by which to measure IQ are discussed in detail in Chapter Two. There is no reason for this investigator to believe that the use of the total IQ test score from this test affects the validity of the study.

Statistical Regression.-- Where groups have been selected on the basis of their extreme scores, there is often the tendency in subsequent testing for these groups to display regression to the mean. This factor was not considered to be a threat to the present study, and there was no means to examine data for the existence of such a phenomenon in the present study.

Selection.-- On a broad scale, the use of the school district implies the possibility of economic selection in subjects. As well, students for use in the study were not randomly picked; both sample populations were chosen as a result of accessibility (in the middle school sample) and presumed variability (in the high school population). In the latter case, self-selection into particular high school classes may affect the overall validity, but the choice of a broad range of subjects (i.e., chemistry, general humanities, English composition, and American novel) is an attempt to address the problem of selection.

Mortality.-- There was a small loss of students on the second day of testing due to absences attributed to illness.

Table 3-2 presents numbers of students in each class absent on the second day of testing.

## Summary Statement of Chapter Three

In order to conduct a descriptive study which validly assesses the relationships between a number of psychological, sociometric, and personological variables, there were a number of concerns which had to be addressed in the conceptualization of the project. Concerns of design, choice of subjects, instrumentation, and statistical analysis which confronted the researcher are outlined in this chapter. Particular factors known to jeopardize the internal validity of behavioral research in general, as outlined by Campbell and Stanley (1973), are also addressed as a major portion of this chapter.

In general it was assumed that the results of the testing of the Hypothesis I would reveal valid information regarding the relationship between pairs of variables included in the study. Also considered as yielding valid information were the age-related examinations of the correlations of Scientific Reasoning and the other variables considered in this study (Hypothesis II). Finally, it was deemed that the formulation of a model of scientific reasoning based on the results of path analytic methods (Hypothesis III) would yield valid results.

# CHAPTER FOUR

## RESULTS

Three general hypotheses were tested in the present research: Hypothesis I, actually a set of hypotheses dealing with the simple relationships between variables in the study; Hypothesis II, a set of hypotheses dealing with the relationships between several variables and scientific reasoning ability for older and younger age groups; and Hypothesis III, a hypothesis that a causal model can be developed depicting the relationships of the variables addressed in this study and scientific reasoning ability. This chapter discusses the results of the testing of these three hypotheses.

### Testing Hypothesis I

Hypothesis I, restated below, posited a number of relationships between variables chosen for study in this research. As a first step in the analysis of the data collected, correlations were computed for all variables included in the study. A matrix of the correlational data is presented in Table 4-1. In considering which of the correlations achieved significance, the desired alpha level of 0.05 was adjusted to accommodate the fact that 14 correlations were being conducted using the same subjects. The corrected alpha level was computed to be 0.004, using the formula below:

$$\text{adjusted alpha} = 1 - (1 - \text{true alpha})^{1/k}$$

where k = number of desired correlations, and alpha = desired alpha level. Significant correlations between variables based on the adjusted alpha are indicated in Table 4-1. All correlation coefficients in this table were subjected to one-tailed tests.

## Hypothesis I

Hypothesis I: There will be significant ($p < 0.05$) correlations between the following pairs of variables:

- I-a. Level of experience and field independence (positive correlation);
- I-b. Level of experience and level of scientific reasoning (positive correlation);
- I-c. Internal locus of control and field independence (positive correlation);
- I-d. Internal locus of control and level of scientific reasoning (positive correlation);
- I-e. Age level and level of experience (positive correlation);
- I-f. Age level and level of flexibility (positive correlation);
- I-g. Age level and level of scientific reasoning (positive correlation);
- I-h. Field independence and level of scientific reasoning (positive correlation);

I-i. Flexibility and field independence (positive correlation);

I-j. Flexibility and scientific reasoning ability (positivecorrelation);

I-k. IQ and scientific reasoning (positive correlation);

I-l. Being female and internal locus of control (negative correlation);

I-m. Being male and level of experience (positive correlation);

I-n. Being male and field independence (positive correlation).

## Hypothesis I-a

It was hypothesized that there would be a significant correlation between level of experience, as measured by the Cognitive and Recreational Activity Scale, and Field Independence, so specified that higher levels of Experience would correspond to field independence. The correlation coefficient between this pair of variables was 0.10 ($p = 0.078$). This hypothesis was not supported.

## Hypothesis I-b

It was hypothesized that there would be a significant correlation between level of Experience and level of Scientific Reasoning. The correlation coefficient between these variables was 0.08 ($p = 0.123$). This hypothesis was not supported.

## TABLE 4-1

### CORRELATION MATRIX FOR ALL VARIABLES CONSIDERED IN THE STUDY

| | CRAS | IAR | AGE | CFT | BRT | IQ | SEX |
|---|---|---|---|---|---|---|---|
| IAR | 0.23*<br>(198) | | | | | | |
| AGE | 0.05<br>(198) | 0.12<br>(198) | | | | | |
| CFT | 0.10<br>(198) | 0.19*<br>(198) | 0.41*<br>(198) | | | | |
| BRT | -0.05<br>(193) | -0.09<br>(193) | -0.34*<br>(193) | -0.19*<br>(193) | | | |
| IQ | -0.04<br>(161) | 0.01<br>(161) | -0.07<br>(161) | 0.30*<br>(161) | -0.07<br>(157) | | |
| SEX | 0.00<br>(198) | 0.07<br>(198) | -0.01<br>(198) | 0.02<br>(198) | -0.08<br>(193) | -0.08<br>(161) | |
| SRT | 0.08<br>(198) | 0.21*<br>(198) | 0.57*<br>(198) | 0.51*<br>(198) | -0.25*<br>(193) | 0.48*<br>(161) | -0.03<br>(198) |

* Indicates significance at the $p <= 0.004$ level (p adjusted to accommodate multiple correlations)

Abbreviations of variables as follows:

CRAS - Cognitive and Recreational Activity Scale (Higher numbers = higher experience)

IAR - Intellectual Achievement Responsibility Questionnaire (Higher numbers = internal locus)

AGE - Chronological Age in years

CFT - Concealed Figures Test (Higher numbers = field independence)

BRT - Breskin's Rigidity Test (Higher numbers = flexibility)

IQ - Short Form Test of Academic Aptitude

SEX - Gender (1=male; 2=female)

SRT - Scientific Reasoning Test

Hypothesis I-c

A significant correlation between Locus of Control and Field Dependence-Independence was hypothesized, in that students exhibiting an internal locus would be field independent. The correlation coefficient resulting between this pair of variables was 0.19 (p = 0.003). This hypothesis was supported.

Hypothesis I-d

It was hypothesized that a significant correlation would exist between Locus of Control and level of Scientific Reasoning, so specified that internal locus would correlate with higher levels of scientific reasoning. The resulting correlation coefficient of 0.21 (p = 0.002) was significant. This hypothesis was supported.

Hypothesis I-e

A significant positive correlation was hypothesized between Age level and level of Experience. The correlation coefficient of 0.05 (p = 0.232) indicated lack of support for this hypothesis.

Hypothesis I-f

It was hypothesized that there would be a significant positive correlation between Age level and Rigidity/Flexibility, with older adolescents being more flexible. A correlation coefficient of -0.34 ($p < 0.001$) indicated the existence of a relationship between the two variables. However, the obtained negative correlationwas not hypothesized. This hypothesis was therefore not supported.

### Hypothesis I-g

A significant positive relationship was hypothesized between Age level and Scientific Reasoning. The correlation coefficient of 0.57 ($p < 0.001$) obtained between the two variables resulted in support of this hypothesis.

### Hypothesis I-h

It was hypothesized that a significant correlation would result between Field Dependence-Independence and level of Scientific Reasoning, with those individuals exhibiting field independence also exhibiting higher levels of scientific reasoning. A correlation coefficient of 0.51 ($p < 0.001$) resulted between the two variables. This hypothesis was therefore supported.

### Hypothesis I-i

A significant positive correlation between Rigidity/Flexibility and Field Dependence-Independence was hypothesized, with individuals exhibiting high levels of flexibility also exhibiting field independence. A correlation coefficient of -0.19 ($p = 0.004$) resulted between the two variables. As with Hypothesis I-f which also involved the flexibility variable, the relationship between the two variables was negative rather than positive. This hypothesis was therefore not supported.

### Hypothesis I-j

Rigidity/Flexibility and Scientific Reasoning were hypothesized to be positively correlated, with higher levels of flexibility being associated with higher levels of scientific reasoning. A correlation coefficient of -0.25 ($p < 0.001$) indicated a negative correlation rather than a positive one. This hypothesis was therefore not supported.

### Hypothesis I-k

A significant positive correlation between IQ and Scientific Reasoning ability was hypothesized. The resulting correlation coefficient of 0.48 ($p < 0.001$) supported this hypothesis.

### Hypothesis I-l

It was hypothesized that a significant, negative correlation would exist between being Gender and Locus of Control, so that females would exhibit characteristics of external individuals. The correlation coefficient of 0.07 ($p = 0.164$) between these two variables did not support this hypothesis.

### Hypothesis I-m

A significant positive correlation was hypothesized between Gender and level of Experience, with males exhibiting higher levels of experience. This hypothesis was not supported; the correlation coefficient between these two variables was 0.004 ($p = 0.477$).

### Hypothesis I-n

It was hypothesized that a significant positive relationship would exist between Gender and Field Dependence-Independence, with males being more field independent. A correlation coefficient between these two variables of 0.014 ($p = 0.148$) did not support this hypothesis.

### Summary of Hypothesis I Findings

Fourteen sub-hypotheses which were posited involved relationships between variables as stated in Hypothesis I. Five of the 14 were significant at the corrected alpha level of 0.004 and were supported, as listed below:

I-c. Locus of Control and FDI ($r = 0.19$, $p = 0.003$),

I-d. Locus of Control and Scientific Reasoning ($r = 0.21$, $p < 0.002$),

I-g. Age and Scientific Reasoning ($r = 0.57$, $p < 0.001$),

I-h. Field Dependence-Independence and Scientific Reasoning ($r = 0.51$, $p < .001$), and

I-k. IQ and Scientific Reasoning ($r = 0.48$, $p < 0.001$).

The three hypotheses involving the Rigidity/Flexibility construct were hypothesized to be positively correlated but resulted in negative correlations (Hypotheses I-f, I-i and I-j). These three hypotheses were rejected on this basis. The correlation coefficients obtained between the Rigidity/Flexibility construct and Scientific Reasoning (-0.51), Field Independence (-0.19), and Age (-0.34) indicate that relationships exist amoung these variables.

Of those hypotheses which were supported, Hypotheses I-c and I-d involved relationships of Locus of Control with Field Independence and level of Scientific Reasoning, respectively. Support for Hypotheses I-g, I-h, and I-k resulted in the identification of three correlates of Scientific Reasoning: Age level, Field Independence, and IQ.

## Testing Hypothesis II

Testing Hypothesis II, as restated below, involved the analysis of differences between coefficients of correlation for pairs of variables in two groups, the younger and older adolescent populations. The method employed for the analyses of these group differences is outlined in Guilford and Fruchter (1978, p. 163). This method uses Fisher's transformation of correlation coefficients to Z-scores. The standard error of a difference between two such Z's is computed by the formula:

$$sd_z = \sqrt{\frac{1}{N_1 - 3} + \frac{1}{N_2 - 3}}$$

The two correlation coefficients being compared are converted to Z coefficients using any standard table of Z values. The difference between the two Z coefficients being compared is divided by the computed standard error. A table which presents the areas and ordinates of the normal curve is then consulted to determine the area in the smaller portion of the normal curve (alpha level) which corresponds to the resulting Z score. (Table B in Guilford and Fruchter, pp. 503-510 was consulted in this study.) Values of N and correlation coefficients with corresponding Z coefficients are presented in Table 4-2.

## TABLE 4-2

## CORRELATION COEFFICIENTS, THEIR CORRESPONDING Z COEFFICIENTS AND N'S FOR YOUNGER AND OLDER ADOLESCENT SAMPLES WITH COMPUTED DIFFERENCES IN Z AND THEIR CORRESPONDING LEVELS OF SIGNIFICANCE

| VARIABLE PAIR | AGE GROUP[a] | n | r | Z | Z Diff. (ALPHA) |
|---|---|---|---|---|---|
| IQ and Scientific Reasoning | 1 | 85 | 0.70 | 0.87 | 1.55 (.60) |
| | 2 | 76 | 0.55 | 0.62 | |
| Field Independence and Scientific Reasoning | 1 | 106 | 0.39 | 0.41 | 0.14 (.24) |
| | 2 | 92 | 0.30 | 0.31 | |
| Locus of Control and Scientific Reasoning | 1 | 106 | 0.13 | 0.13 | 0.00 |
| | 2 | 92 | 0.13 | 0.13 | |
| Experience and Scientific Reasoning | 1 | 106 | 0.07 | 0.07 | 0.64 (.26) |
| | 2 | 92 | -0.02 | -0.02 | |

[a] Grouping: 1 = indicates the younger sample
2 = indicates the older sample

## Hypothesis II

Hypothesis II. Group effects, as based upon age, are hypothesized so that there will be a significant difference in the amount of explained variance between the following pairs of variables in the younger and older adolescent populations:

II-a. IQ and scientific reasoning, with IQ sharing a higher amount of variance with scientific reasoning in the younger population;

II-b. Field independence and scientific reasoning, with field independence sharing a higher amount of variance with scientific reasoning in the older population;

II-c. Internal locus of control and scientific reasoning, with internal locus of control a higher amount of variance with scientific reasoning in the younger population;

II-d. Experience and scientific reasoning, with experience sharing to a higher amount of variance with scientific reasoning in the older population.

## Hypothesis II-a

It was hypothesized that age group effects would be significant for relationships between IQ and scientific reasoning. The correlation coefficients for the two age groups of 0.70 and 0.55 were converted to Z scores of 0.87 and 0.62, respectively, for the younger and older samples. The difference in Z scores of 1.55 between these two variables was significant at the 0.60 level. Hypothesis II-a could not be supported, as the desired 0.05 level was not attained.

### Hypothesis II-b

It was hypothesized that the age group difference in correlation coefficients of field independence and scientific reasoning would be significant. Procedures as outlined above were followed for N's of 106 and 92 for younger and older adolescent populations, respectively. Correlation coefficients of 0.39 and 0.30 were transformed to Z scores of 0.41 and 0.31. The resulting Z score of the difference between the two was 0.14. The level of significance for that value was 0.25. Hypothesis II-b was therefore not supported.

### Hypothesis II-c

A significant difference in the correlation coefficients of locus of control and scientific reasoning was hypothesized for the two adolescent populations. N's of 106 and 92 were used to calculate the standard error of the difference between the two Z coefficients. Transformed Z coefficients of 0.13 and 0.13 resulted from original correlation coefficients of 0.13 and 0.13. Further calculations were therefore not necessary. Hypothesis II-c was not supported.

### Analysis of Hypothesis II-d

A significant age group difference between correlation coefficients of experience and scientific reasoning ability was hypothesized. Correlation coefficients of 0.07 and -0.02 were converted to Z coefficients, resulting in values of 0.07 and -0.02 for the younger and older populations, respectively. A computed Z score difference of 0.64, when divided by the appropriate standard error, indicated a level of significance of 0.26. This hypothesis was not supported on the basis of these findings.

## Summary of Hypothesis II Findings

Group effects, as based upon age, did not exist for any of the hypothesized relationships of variables with scientific reasoning ability. Hypothesis II-a showed the most promising relationship in terms of the obtained significance level of 0.06.

## Testing Hypothesis III

Hypothesis III, as stated below, posits that a model for the direct and indirect effects of a number of variables on scientific reasoning ability can be developed and tested. To test this hypothesis, a causal model was formulated on the basis of previous research reports, theoretical considerations, and the results of the pilot project performed subsequent to the final study. The information from these sources are outlined in detail in Chapter Two.

Hypothesized paths were tested by regression techniques in which each endogenous variable was regressed by variables impinging upon it, with the last variable entered in the regression representing the determinant of the dependent variable in path being examined. The standardized beta weight for the determinant variable obtained from the regression was then used as the path coefficient for the path, as outlined by Pedhazur (1982). Beta weights which were significant at the alpha level of 0.05 indicated significant path coefficients which were then included in the final, simplified model. Paths not significant at the 0.05 level were removed. Regressions were then performed as above to test each of the remaining paths.

## Hypothesis III

Hypothesis III. A causal model can be developed for experience, locus of control, age, field dependence-independence, flexibility/rigidity, IQ, gender, and scientific reasoning, where significant path coefficients will confirm each relationship as indicated by the path diagram in Figure 1.1.

The hypothesized causal model of Hypothesis III, appearing as Figure 4-1, was tested by regression techniques in which path coefficients were calculated for each of the paths indicated by arrows in the figure. The results of calculating the path coefficients by simple and multiple regression analyses are discussed in the following order, after the order of discussion followed in Chapter Two:

P84, Experience to Scientific Reasoning
P74, Experience to Field Dependence-Independence

P85, Locus of Control to Scientific Reasoning
P75, Locus of Control to Field Dependence-Independence

P41, Age to Experience
P61, Age to Rigidity/Flexibility
P81, Age to Scientific Reasoning

P87, Field Dependence-Independence to Scientific Reasoning

P76, Rigidity/Flexibility to Field Dependence-Independence
P86, Rigidity/Flexibility to Scientific Reasoning

P83, IQ to Scientific Reasoning

P52, Gender to Locus of Control
P42, Gender to Experience
P72, Gender to Field Dependence-Independence

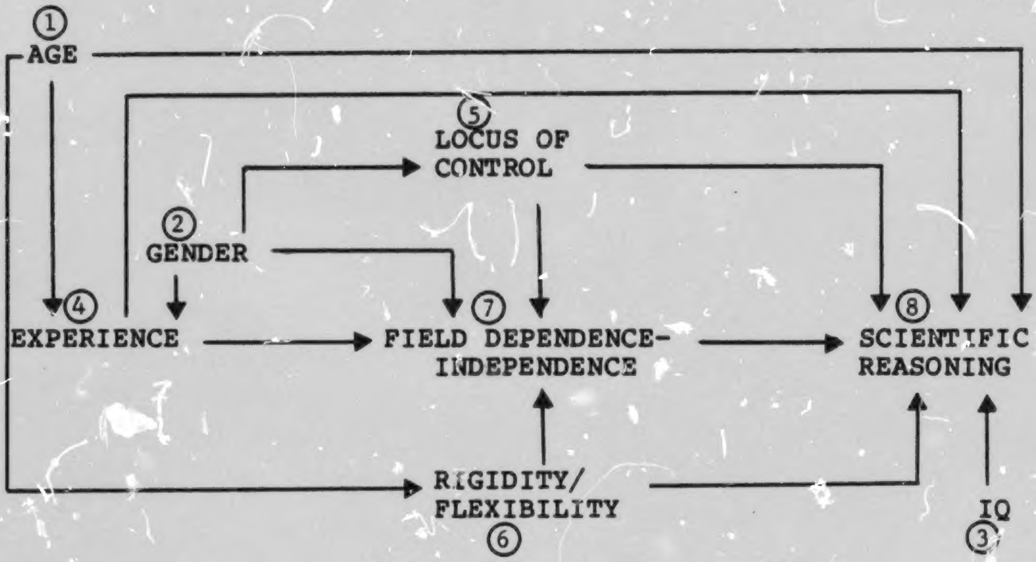

① AGE
② GENDER
③ IQ
④ EXPERIENCE
⑤ LOCUS OF CONTROL
⑥ RIGIDITY/ FLEXIBILITY
⑦ FIELD DEPENDENCE- INDEPENDENCE
⑧ SCIENTIFIC REASONING

Fig. 4-1. A causal model for Scientific Reasoning displaying hypothesized paths between variables which were tested by path analysis techniques. Results from simple and multiple regressions were used to evaluate paths as to their statistical significance, according to the methods outlined in Asher (1976) and Pedhazur (1982).

### Calculation for Path Coefficient P84: Experience to Scientific Reasoning

In calculating the path coefficient P84, a regression was performed in which Scientific Reasoning was first regressed by the variables Field Dependence- Independence, Rigidity/Flexibility, IQ, Locus of Control, and Age. This regression represented the removal of the effects of variables not unique to the Experience variable. The Experience variable was then entered into the regression equation and the obtained beta identified for use as a path coefficient. Table 4-3 represents results of both the initial multiple regresssion and the subsequent regression by the Experience variable. The value of path coefficient P84 was 0.11, which was found to be significant at <0.01.

TABLE 4-3

MULTIPLE REGRESSION TO DETERMINE THE PATH COEFFICIENT P84
(FROM EXPERIENCE TO SCIENTIFIC REASONING)

| | Beta | SE | $R^2$ | Ch.$R^2$ | T | p |
|---|---|---|---|---|---|---|
| Initial Variables Removed: | | | | | | |
| Field Dep-Ind | 0.14 | 0.06 | | | 2.31 | 0.02 |
| Rigid/Flex | -0.02 | 0.05 | | | -0.46 | 0.65 |
| IQ | 0.49 | 0.05 | | | 9.08 | <0.01 |
| Locus | 0.05 | 0.05 | | | 0.96 | 0.33 |
| Age | 0.53 | 0.06 | 0.61 | 0.61 | 9.03 | <0.01 |
| Path Variable: | | | | | | |
| Experience | 0.11 | 0.05 | 0.62 | 0.01 | 2.06 | <0.01 |

Calculation of Path Coefficient P74: Experience to Field Dependence-Independence

To calculate the path coefficient P74, the variable Field Dependence-Independence was first regressed by the variables Rigidity/Flexibility, Sex, and Locus of Control. This regression represented the removal of effects not attributed to the Experience variable. The beta which was obtained when Experience was entered into the regression was identified for use as the path coefficient P74. Table 4-4 represents results of the intial multiple regression and the subsequent regression by Experience. The path coefficient obtained for P74 was -0.11 ($p = 0.78$), the beta obtained after the addition of the Experience variable.

TABLE 4-4

MULTIPLE REGRESSION TO DETERMINE THE PATH COEFFICIENT P74
(FROM EXPERIENCE TO FIELD DEPENDENCE-INDEPENDENCE)

| | Beta | SE | $R^2$ | Ch.$R^2$ | T | p |
|---|---|---|---|---|---|---|
| Initial Variables Removed: | | | | | | |
| Rigid/Flex | -0.12 | 0.08 | | | -1.61 | 0.11 |
| Sex | 0.02 | 0.08 | | | 0.31 | 0.76 |
| Locus | 0.28 | 0.08 | 0.10 | 0.10 | 3.58 | <0.01 |
| Path Variable: | | | | | | |
| Experience | 0.11 | 0.05 | 0.10 | 0.00 | -0.28 | 0.78 |

## Calculation of Path Coefficient P85: Locus of Control to Scientific Reasoning

Path coefficient P85 was calculated by first removing the effects of these variables: Field Dependence-Independence, Experience, Regidity/Flexibility, IQ, and Age. This regression represented the removal of effects not unique to the Locus of Control variable. When Locus of Control was entered into the regression equation, a beta weight of 0.05, significant at 0.34, was obtained. This beta weight was used as the path coefficient for P85. Results of this multiple regression are reported in Table 4-5.

### TABLE 4-5

MULTIPLE REGRESSION TO DETERMINE THE PATH COEFFICIENT P85
(FROM LOCUS OF CONTROL TO SCIENTIFIC REASONING)

| | Beta | SE | $R^2$ | Ch.$R^2$ | T | p |
|---|---|---|---|---|---|---|
| Initial Variables Removed: | | | | | | |
| Field Dep-Ind | 0.15 | 0.06 | | | 2.61 | 0.01 |
| Experience | 0.11 | 0.05 | | | 2.23 | 0.03 |
| Rigid/Flex | -0.03 | 0.05 | | | -0.49 | 0.63 |
| IQ | 0.49 | 0.05 | | | 9.06 | <0.01 |
| Age | 0.53 | 0.06 | 0.61 | 0.61 | 9.16 | <0.01 |
| Path Variable: | | | | | | |
| Locus | 0.05 | 0.05 | 0.61 | 0.00 | 0.96 | 0.34 |

Calculation of Path Coefficient P75: Locus of Control to Field Dependence-Independence

In the calculations for path coefficient P75, Field Dependence-Independence was first regressed by the initial variables of Rigidity/Flexibility, Experience, and Gender. Then Locus of Control was entered into the regression equation. The obtained beta weight of 0.28, significant at <0.01, was identified as the path coefficient for P75. Table 4-6 represents results of both the initial multiple regression and the subsequent regression by the Locus of Control variable.

TABLE 4-6

MULTIPLE REGRESSION TO DETERMINE THE PATH COEFFICIENT P75 (FROM LOCUS OF CONTROL TO FIELD DEPENDENCE-INDEPENDENCE)

| | Beta | SE | $R^2$ | Ch.$R^2$ | T | p |
|---|---|---|---|---|---|---|
| Initial Variables Removed: | | | | | | |
| Rigid/Flex | -0.12 | 0.08 | | | -1.61 | 0.11 |
| Experience | -0.02 | 0.08 | | | -0.28 | 0.78 |
| Gender | 0.02 | 0.08 | 0.03 | 0.03 | 0.28 | 0.78 |
| Path Variable: | | | | | | |
| Locus | 0.28 | 0.08 | 0.10 | 0.08 | 3.57 | <0.01 |

Calculation of Path Coefficient P41: Age to Experience

In the initial regressions for the calculation of path coefficient P41, Experience was regressed by the Gender variable in order to remove the effects not unique to the variable of Age. Age was then entered into the regression equation and the beta weight of -0.01 (p = 0.93) was obtained. This beta weight was used as the path coefficient for P41. Results of both the regressions are presented in Table 4-7.

TABLE 4-7

MULTIPLE REGRESSION TO DETERMINE THE PATH COEFFICIENT P41
(FROM AGE TO EXPERIENCE)

| | Beta | SE | $R^2$ | Ch.$R^2$ | T | p |
|---|---|---|---|---|---|---|
| Initial Variable Removed: | | | | | | |
| Gender | -0.08 | 0.08 | 0.01 | 0.01 | -0.09 | 0.93 |
| Path Variable: | | | | | | |
| Age | -0.01 | 0.01 | 0.01 | 0.01 | -0.09 | 0.93 |

Calculation of Path Coefficient P61: Age to Rigidity/Flexibility

In the calculation of this path coefficient, a simple regression was done in which Rigidity/Flexibility was regressed by the variable Age. There were no other effects from other variables on the Age variable. The beta weight of -0.32, significiant at <0.01, resulted from this regression was used as the path coefficient P61. Results of the simple regression are represented in Table 4-8.

TABLE 4-8

SIMPLE REGRESSION TO DETERMINE THE PATH COEFFICIENT P61
(FROM AGE TO RIGIDITY/FLEXIBILITY)

| | Beta | SE | $R^2$ | Ch.$R^2$ | T | p |
|---|---|---|---|---|---|---|
| Path Variable: | | | | | | |
| Age | -0.32 | 0.08 | 0.10 | 0.10 | -4.20 | <0.01 |

### Calculation of Path Coefficient P81: Age to Scientific Reasoning

Effects not unique to the Age variable were initially removed by a multiple regression in which Scientific Reasoning was regressed by the variables Field Dependence-Independence, Rigidity/Flexibility, IQ, and Locus of Control. The Age variable was then entered into the regression equation and the obtained beta of 0.53, significant at <0.01, used as a path coefficient for the path P81. Results of both the initial multiple regression and the subsequent regression by Age are presented in Table 4-9.

TABLE 4-9

MULTIPLE REGRESSION TO DETERMINE THE PATH COEFFICIENT P81
(FROM AGE TO SCIENTIFIC REASONING)

| | Beta | SE | $R^2$ | Ch.$R^2$ | T | p |
|---|---|---|---|---|---|---|
| Initial Variables Removed: | | | | | | |
| Field Dep-Ind | 0.14 | 0.06 | | | 2.31 | 0.02 |
| Experience | 0.11 | 0.05 | | | 2.06 | 0.04 |
| Rigid/Flex | -0.02 | 0.05 | | | -0.46 | 0.64 |
| IQ | 0.49 | 0.05 | | | 9.08 | <0.01 |
| Locus | 0.05 | 0.05 | 0.41 | 0.41 | 0.96 | 0.34 |
| Path Variable: | | | | | | |
| Age | 0.53 | 0.06 | 0.62 | 0.21 | 9.03 | <0.01 |

### Calculation of Path Coefficient P87: Field Dependence-Independence to Scientific Reasoning

In the calculations for path coefficient P87, a regression was performed in which Scientific Reasoning was initially regressed by these variables: Rigidity/Flexibility, Experience, Locus of Control, and Age. The results of this multiple regression and the subsequent regression by Field Dependence-Independence are represented in Table 4-10. The addition of Field Dependence-Independence yielded a beta of 0.14, significant at 0.02, which was used as the path coefficient P87.

## TABLE 4-10

MULTIPLE REGRESSION TO DETERMINE THE PATH COEFFICIENT P87
(FROM FIELD DEPENDENCE-INDEPENDENCE TO SCIENTIFIC REASONING)

| | Beta | SE | $R^2$ | Ch.$R^2$ | T | p |
|---|---|---|---|---|---|---|
| Initial Variables Removed: | | | | | | |
| Rigid/Flex | -0.02 | 0.05 | | | -0.46 | 0.65 |
| Experience | 0.11 | 0.05 | | | 2.06 | 0.04 |
| IQ | 0.49 | 0.05 | | | 9.08 | <0.01 |
| Locus | 0.05 | 0.05 | | | 0.96 | 0.33 |
| Age | 0.53 | 0.06 | 0.60 | 0.60 | 9.03 | <0.01 |
| Path Variable: | | | | | | |
| Field Dep-Ind | 0.14 | 0.06 | 0.62 | 0.02 | 2.31 | 0.02 |

### Calculation of Path Coefficient P76: Rigidity/Flexibility to Field Dependence-Independence

In order to determine the path coefficient P76, the effects not unique to the Rigidity/Flexibility variable were removed by a multiple regression in which Field Dependence-Independence was regressed by the following variables: Locus of Control, Gender, and Experience. Rigidity/Flexibility was then entered into the regression equation. The obtained beta weight, -0.02 ($p = 0.11$), was used for path coefficient P76. Results of both the initial multiple regression and the subsequent regression by Rigidity/Flexibility are presented in Table 4-11.

## TABLE 4-11

MULTIPLE REGRESSION TO DETERMINE THE PATH COEFFICIENT P76 (FROM RIGIDITY/FLEXIBILITY TO FIELD DEPENDENCE-INDEPENDENCE)

| | Beta | SE | $R^2$ | $Ch.R^2$ | T | p |
|---|---|---|---|---|---|---|
| Initial Variables Removed: | | | | | | |
| Locus | 0.29 | 0.08 | | | 3.71 | <0.01 |
| Gender | 0.03 | 0.08 | | | 0.43 | 0.67 |
| Experience | -0.02 | 0.08 | 0.09 | 0.09 | -0.26 | 0.79 |
| Path Variable: | | | | | | |
| Rigid/Flex | -0.12 | 0.05 | 0.09 | 0.00 | -1.61 | 0.11 |

### Calculation of Path Coefficient P86: Rigidity/Flexibility to Scientific Reasoning

To calculate path coefficient P86, Scientific Reasoning was intially regressed by these variables: Field Dependence-Independence, Experience, IQ, Locus of Control, and Age. This regression represented the removal of effects not unique to the Rigidity/Flexibility variable. Rigidity/Flexibility was then entered into the regression equation, and a beta weight of -0.02 (p = 0.65) was used as the path coefficient for P85. The results of the intial multiple regression and the addition of the Rigidity/Flexibility variable are reported in Table 4-12.

### TABLE 4-12

### MULTIPLE REGRESSION TO DETERMINE THE PATH COEFFICIENT P86 (FROM RIGIDITY/FLEXIBILITY TO SCIENTIFIC REASONING)

| | Beta | SE | $R^2$ | Ch.$R^2$ | T | p |
|---|---|---|---|---|---|---|
| Initial Variables Removed: | | | | | | |
| Field Dep-Ind | 0.14 | 0.06 | | | 2.31 | 0.02 |
| Experience | 0.11 | 0.05 | | | 2.07 | 0.04 |
| IQ | 0.49 | 0.05 | | | 9.18 | <0.01 |
| Locus | 0.05 | 0.05 | | | 0.97 | 0.33 |
| Age | 0.53 | 0.06 | 0.62 | 0.62 | 9.03 | <0.01 |
| Path Variable: | | | | | | |
| Rigid/Flex | -0.02 | 0.06 | 0.62 | 0.00 | -0.46 | 0.65 |

**Calculation of Path Coefficient P83: IQ to Scientific Reasoning**

An initial regression was performed to remove the effects of variables other than IQ on Scientific Reasoning. Variables intially entered in to the equation were: Field Dependence-Independence, Experience, Rigidity/Flexibility, Locus of Control, and Age. The variable IQ was then entered into the equation. A resulting beta of 0.49, significant at <0.01, was used for path coefficient P83. Results of the multiple regression and subsequent addition of the IQ variable appear in Table 4-13.

## TABLE 4-13

### MULTIPLE REGRESSION TO DETERMINE THE PATH COEFFICIENT P83 (FROM IQ TO SCIENTIFIC REASONING)

| | Beta | SE | $R^2$ | Ch.$R^2$ | T | p |
|---|---|---|---|---|---|---|
| Initial Variables Removed: | | | | | | |
| Field Dep-Ind | 0.14 | 0.06 | | | 2.31 | 0.02 |
| Experience | 0.11 | 0.05 | | | 2.06 | 0.04 |
| Rigid/Flex | -0.02 | 0.05 | | | -0.46 | 0.65 |
| Locus | 0.05 | 0.05 | | | 0.96 | 0.34 |
| Age | 0.53 | 0.06 | 0.41 | 0.41 | 9.03 | <0.01 |
| Path Variable: | | | | | | |
| IQ | 0.49 | 0.05 | 0.62 | 0.21 | 9.08 | <0.01 |

### Calculation of Path Coefficient P52: Gender to Locus of Control

In calculating the path coefficient P52, a simple regression was done in which Locus of Control was regressed by the Gender variable. This regression resulted in a beta of 0.09 ($p = 0.29$). The beta of 0.09 was then used as the path coefficient for P52. Results of the simple regression are presented in Table 4-14.

## TABLE 4-14

### SIMPLE REGRESSION TO DETERMINE THE PATH COEFFICIENT P52 (FROM GENDER TO LOCUS OF CONTROL)

| | Beta | SE | $R^2$ | Ch.$R^2$ | T | p |
|---|---|---|---|---|---|---|
| Path Variable: | | | | | | |
| Gender | 0.09 | 0.08 | 0.01 | 0.01 | 1.07 | 0.29 |

Calculation of Path Coefficient P42: Gender to Experience

To calculate the path coefficient P42, a regression was performed in which Experience was first regressed by Age. This regression removed the effects of this variable not unique to the Gender variable. Table 4-15 presents results of both the initial regression and the subsequent regression by Gender. The addition of Gender yielded a beta of -0.08 (p = 0.34), used as the value for path coefficient P42.

## TABLE 4-15

### MULTIPLE REGRESSION TO DETERMINE THE PATH COEFFICIENT P42 (FROM GENDER TO EXPERIENCE)

| | Beta | SE | $R^2$ | Ch.$R^2$ | T | p |
|---|---|---|---|---|---|---|
| Initial Variable Removed: | | | | | | |
| Age | -0.01 | 0.08 | <0.01 | <0.01 | -0.09 | 0.93 |
| Path Variable: | | | | | | |
| Gender | -0.08 | 0.06 | <0.01 | <0.01 | -0.96 | 0.34 |

### Calculation of Path Coefficient P72: Gender to Field Dependence-Independence

In order to calculate the path coefficient P72, an initial multiple regression was performed to remove the effects of variables other than Gender on Field Dependence-Independence. Field Dependence-Independence was first regressed by these variables: Rigidity/Flexibility, Experience, and Locus of Control. Gender was then entered into the regression equation with a resulting beta of 0.02 ($p = 0.78$), used as the path coefficient for P72. Results of both the initial multiple regression and the subsequent regression by Gender is represented in Table 4-16.

TABLE 4-16

MULTIPLE REGRESSION TO DETERMINE THE PATH COEFFICIENT P72
(FROM GENDER TO FIELD DEPENDENCE-INDEPENDENCE)

| | Beta | SE | $R^2$ | Ch.$R^2$ | T | p |
|---|---|---|---|---|---|---|
| Initial Variables Removed: | | | | | | |
| Rigid/Flex | -0.13 | 0.08 | | | -1.65 | 0.10 |
| Experience | -0.02 | 0.08 | | | -0.31 | 0.76 |
| Locus | 0.28 | 0.08 | 0.32 | 0.32 | 3.62 | <0.01 |
| Path Variable: | | | | | | |
| Gender | 0.02 | 0.06 | 0.32 | 0.00 | 0.28 | 0.78 |

## Summary of Initial Calculations for Path Coefficients

Causality between variables in Hypothesis III was posited on the basis of strong theoretical background, heuristic argument, and empirical support, detailed in Chapter Two. A stipulation of causal modeling is that directionality in relationships between variables be made a priori, and that potential determinants be selected with careful consideration of all prior evidence regarding a causal relationship. The model as it originally appeared in Figure 4-1 was formulated with substantial confidence. It was, however, an exploratory attempt to acquire evidence for the direct and indirect effects of a number of variables impinging upon Scientific Reasoning.

The path coefficients which were obtained by single and multiple regression analyses appear in Figure 4-2. These coefficients were used in two ways in testing the hypothesized model: (1) they provided an indication of the relative strengths of the posited causal relationships between the variables in the model; (2) and the resulting alpha level from the addition of the variable hypothesized as determinant provided a criterion of statistical significance, arbitrarily set for this study at an alpha level <= 0.05. Paths, beta weights, and probability levels resulting from the 14 regressions performed in the preliminary regression analyses are presented in Table 4-17.

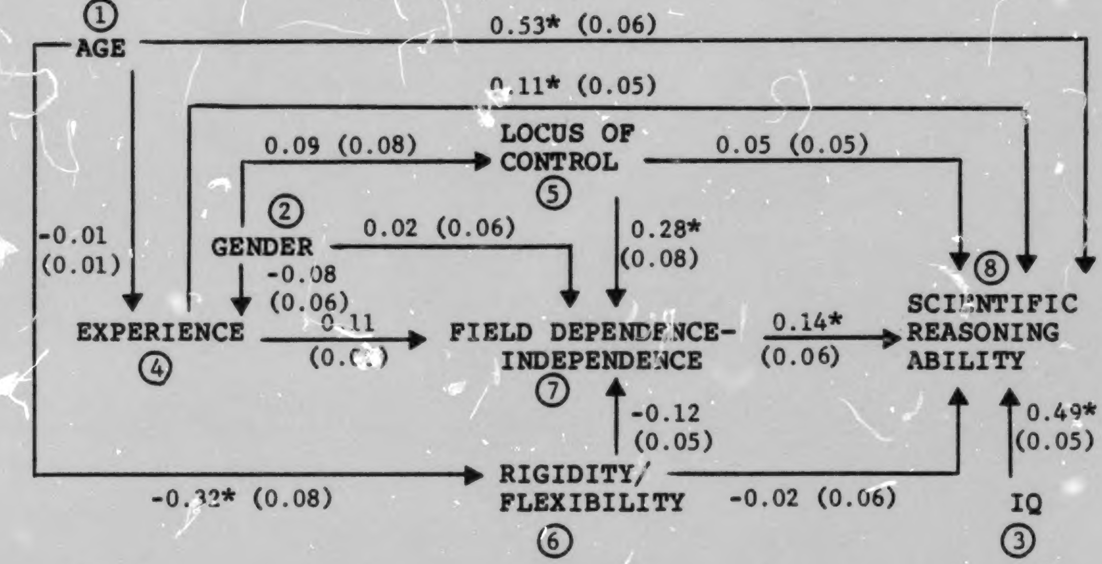

① AGE
0.53* (0.06)
0.11* (0.05)
0.09 (0.08)
LOCUS OF CONTROL ⑤
0.05 (0.05)
-0.01 (0.01)
② GENDER
0.02 (0.06)
0.28* (0.08)
-0.08 (0.06)
⑧ SCIENTIFIC REASONING ABILITY
EXPERIENCE ④
0.11 (0.0[illegible])
FIELD DEPENDENCE-INDEPENDENCE ⑦
0.14* (0.06)
-0.12 (0.05)
0.49* (0.05)
RIGIDITY/ FLEXIBILITY ⑥
-0.32* (0.08)
-0.02 (0.06)
IQ ③

Fig. 4-2. A causal model displaying path coefficients and their corresponding standard errors (in parentheses) obtained from regression analyses. Asterisks indicate statistically significant path coefficients (p <= 0.05) as determined on the basis of exact t-tests performed by the SPSS New Regression Program. -- A general rule of thumb places the level of significance for path coefficients involving high N's at approximately 2 times the standard error of the path coefficient (Lewis-Beck, 1980).

### TABLE 4-17

### SUMMARY OF REGRESSIONS FROM WHICH ORIGINAL PATH COEFFICIENTS WERE OBTAINED FOR TESTING THE CAUSAL MODEL OF SCIENTIFIC REASONING

| Path | From | To | Beta | p |
|---|---|---|---|---|
| P84 | Experience | Scientific Reasoning | 0.11 | <0.02* |
| P74 | Experience | Field Dep-Ind | 0.11 | 0.78 |
| P85 | Locus | Scientific Reasoning | 0.05 | 0.34 |
| P75 | Locus | Field Dep-Ind | 0.28 | <0.01* |
| P41 | Age | Experience | -0.01 | 0.93 |
| P61 | Age | Rigid/Flex | -0.32 | <0.01* |
| P81 | Age | Scientific Reasoning | 0.53 | <0.01* |
| P87 | Field Dep-Ind | Scientific Reasoning | 0.14 | 0.02* |
| P76 | Rigid/Fle | Field Dep-Ind | -0.12 | 0.11 |
| P86 | Rigid/Flex | Scientific Reasoning | -0.02 | 0.65 |
| P83 | IQ | Scientific Reasoning | 0.49 | <0.01* |
| P52 | Gender | Locus of Control | 0.09 | 0.29 |
| P42 | Gender | Experience | -0.08 | 0.34 |
| P72 | Gender | Field Dep-Ind | 0.02 | 0.78 |

*Indicates statistical significance at alpha <= 0.5

Of the 14 path coefficients derived by the process of regressing variables as potential determinants of the dependent variable, six were significant at the alpha level of p <= 0.05. These paths are listed as follows: P84, Experience to Scientific Reasoning; P75, Locus of Control to Field Dependence-Independence; P61, Age to Rigidity/ Flexibility; P81, Age to Scientific Reasoning; P87, Field Dependence-Independence to Scientific Reasoning; and P83, IQ to Scientific Reasoning. On the basis of the level of significance obtained for the beta weights derived by regression techniques, the model was "trimmed," as discussed by Pedhazur (1982). Path coefficients with levels of significance greater than 0.05 were eliminated from the final model. As well, the path from Age to Rigidity/Flexibility was eliminated, as there were no subsequent paths from the Rigidity/Flexibility variable which impinged directly or indirectly on the ultimate dependent variable of interest, Scientific Reasoning. The simplified model which was subjected to final analysis appears in Figure 4-3. Subsequent analyses on the remaining five paths, as indicated in Figure 4-3, were performed using simple and multiple regression techniques as described previously. The discussions which follow detail the results of these regression procedures which were performed in order to obtain the path coefficients for the revised and simplified causal model of Scientific Reasoning.

## Calculation of the Revised Path Coefficient P84: Experience to Scientific Reasoning

Procedures similar to those described previously for obtaining path coefficients were employed to calculate the revised path coefficient P84. Scientific Reasoning was first regressed by Field Dependence-Independence, IQ, and Age. Experience was entered into the regression equation after effects not unique to the Experience variable were removed. Table 4-18 represents results of the initial multiple regression equation and the subsequent regression by Experience. The beta of 0.11, significant at 0.02, yielded the revised path coefficient for P84.

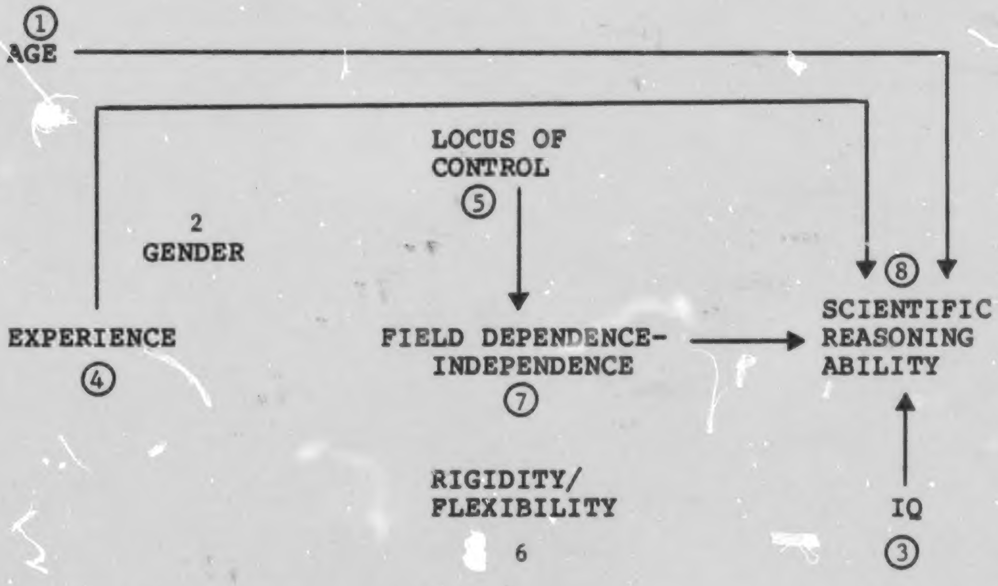

①
AGE
LOCUS OF
CONTROL
⑤
2
GENDER
⑧
SCIENTIFIC
REASONING
ABILITY
EXPERIENCE
④
FIELD DEPENDENCE-
INDEPENDENCE
⑦
RIGIDITY/
FLEXIBILITY
6
IQ
③

Fig. 4-3. A simplified causal model displaying the statistically significant ($p < 0.05$) relationships which resulted from the testing of the postulated model of Hypothesis III.

## TABLE 4-18

## MULTIPLE REGRESSION TO DETERMINE THE REVISED PATH COEFFICIENT P84 (FROM EXPERIENCE TO SCIENTIFIC REASONING)

| | Beta | SE | $R^2$ | Ch.$R^2$ | T | p |
|---|---|---|---|---|---|---|
| Initial Variables Removed: | | | | | | |
| Field Dep-Ind | 0.16 | 0.06 | | | 2.68 | <0.01 |
| IQ | 0.49 | 0.05 | | | 8.95 | <0.01 |
| Age | 0.54 | 0.06 | 0.60 | 0.60 | 9.60 | <0.01 |
| Path Variable: | | | | | | |
| Experience | 0.11 | 0.05 | 0.61 | 0.01 | 2.24 | <0.01 |

### Calculation of Revised Path Coefficient P81: Age to Scientific Reasoning

In calculating the revised path coefficient P81, these variables were first regressed on Scientific Reasoning: Field Dependence-Independence, Experience, and IQ. This regression removed the effects of variables other than the Age variable. Age was then entered into the regression equation and the obtained beta of 0.54, significant at <0.01, identified as the revised path coefficient for P81. Table 4-19 summarizes results of the initial multiple regression and subsequent regression by age.

## TABLE 4-19

## MULTIPLE REGRESSION TO DETERMINE THE REVISED PATH COEFFICIENT P81 (FROM AGE TO SCIENTIFIC REASONING)

| | Beta | SE | $R^2$ | Ch.$R^2$ | T | p |
|---|---|---|---|---|---|---|
| Initial Variables Removed: | | | | | | |
| Field Dep-Ind | 0.15 | 0.06 | | | 2.62 | <0.01 |
| Experience | 0.11 | 0.05 | | | 2.24 | 0.02 |
| IQ | 0.49 | 0.05 | 0.37 | 0.37 | 9.17 | <0.01 |
| Path Variable: | | | | | | |
| Age | 0.54 | 0.06 | 0.61 | 0.24 | 9.78 | <0.01 |

### Calculation of Revised Path Coefficient P83: IQ to Scientific Reasoning

Scientific Reasoning was initially regressed by a number of variables in order to remove effects not unique to the IQ variable. These variables were: Field Dependence-Independence, Experience, and Age. IQ was then entered into the regression equation and a beta of 0.49, significant at <0.01, was obtained which was used for the revised path coefficient P83. Table 4-20 summarizes results of both the initial multiple regression and the subsequent regression of IQ on Scientific Reasoning.

TABLE 4-20

MULTIPLE REGRESSION TO DETERMINE THE REVISED PATH COEFFICIENT P83 (FROM IQ TO SCIENTIFIC REASONING

| | Beta | SE | $R^2$ | Ch.$R^2$ | T | p |
|---|---|---|---|---|---|---|
| Initial Variables Removed: | | | | | | |
| Field Dep-Ind | 0.15 | 0.06 | | | 2.62 | <0.01 |
| Experience | 0.11 | 0.05 | | | 2.24 | 0.02 |
| Age | 0.54 | 0.06 | 0.40 | 0.40 | 9.78 | <0.01 |
| Path Variable: | | | | | | |
| IQ | 0.49 | 0.05 | 0.61 | 0.21 | 9.17 | <0.01 |

### Calculation of Revised Path Coefficient P87: Field Dependence-Independence to Scientific Reasoning

Revised path coefficient P87 was calculated by first removing the effects of variables not unique to the Field Dependence-Independence variable. Scientific Reasoning was first regressed by the variables, Experience, Age, and IQ. Field Dependence-Independence was then entered into the equation. An obtained beta of 0. 15, significant at $p < 0.01$, was then used as the path coefficient for revised path P87. Table 4-21 summarizes the results of the initial and subsequent regressions of these variables on Scientific Reasoning.

## TABLE 4-21

## MULTIPLE REGRESSION TO DETERMINE THE REVISED PATH COEFFICIENT P87 (FROM FIELD DEPENDENCE-INDEPENDENCE TO SCIENTIFIC REASONING)

| | Beta | SE | $R^2$ | $Ch.R^2$ | T | p |
|---|---|---|---|---|---|---|
| Initial Variables Removed: | | | | | | |
| Experience | 0.11 | 0.05 | | | 2.24 | 0.02 |
| Age | 0.54 | 0.06 | | | 9.78 | <0.01 |
| IQ | 0.49 | 0.05 | 0.60 | 0.60 | 9.17 | <0.01 |
| Path Variable: | | | | | | |
| Field Dep-Ind | 0.15 | 0.06 | 0.61 | 0.01 | 2.62 | <0.01 |

### Calculation of Revised Path Coefficient P75: Locus of Control to Field Dependence-Independence

A simple regression was performed in order to calculated the revised path coefficient P75. Field Dependence-Independence was regressed by the Locus of Control variable. The resulting beta of 0.29, significant at <0.01, was used as the revised path coefficient P75. The results regression of Field Dependence-Independence by Locus of Control are represented in Table 4-22.

## TABLE 4-22

## SIMPLE REGRESSION TO DETERMINE THE REVISED PATH COEFFICIENT P75 (FROM LOCUS OF CONTROL TO FIELD DEPENDENCE-INDEPENDENCE)

| | Beta | SE | $R^2$ | Ch.$R^2$ | T | p |
|---|---|---|---|---|---|---|
| Path Variable: | | | | | | |
| Locus | 0.29 | 0.08 | 0.08 | 0.08 | 3.79 | <0.01 |

### Summary of Procedures Resulting in Revised Path Coefficients

Five regressions were performed in order to obtain the revised path coefficients for the simplified model of scientific reasoning which appeared as Figure 4-3. Four of these were multiple regressions involving the Scientific Reasoning variable as the dependent variable, resulting in revised path coefficients for paths P84, P81, P83, and P87. The calculation of the fifth path coefficient, P75, involved a simple regression of Field Dependence-Independence by Locus of Control. Table 4-23 summarizes the results of these five regressions from which the eventual path coefficients were obtained for the simplified model of Scientific Reasoning.

TABLE 4-23

SUMMARY OF REGRESSIONS FROM WHICH REVISED PATH COEFFICIENTS WERE OBTAINED FOR THE SIMPLIFIED CAUSAL MODEL FOR SCIENTIFIC REASONING

| Path | From | To | Beta | p |
|---|---|---|---|---|
| P84 | Experience | Scientific Reasoning | 0.11 | 0.02 |
| P81 | Age | Scientific Reasoning | 0.54 | <0.01 |
| P83 | IQ | Scientific Reasoning | 0.49 | <0.01 |
| P87 | Field Dep-Ind | Scientific Reasoning | 0.15 | <0.01 |
| P75 | Locus | Field Dep-Ind | 0.29 | <0.01 |

## Post Hoc Theory Modification

On a purely exploratory basis, the original model of Hypothesis III (Figure 4.1) was modified to include a causal relationship between Locus of Control and Experience, which had not been hypothesized previously. This relationship appears in Figure 4-4, the modified model, as P54. In this modification, higher experiences in mental reformulation and spatial visualization activities were postulated to predict the degree to which individuals exhibit an internal locus of control. Although strong support was lacking for originally hypothesizing such a relationship, the investigator sought to obtain some evidence for the existence of another pathway for affecting Scientific Reasoning through the Experience variable. When the original model (Fig. 4.1) was tested, evidence was found for significant direct effects of Experience on Scientific Reasoning, indicated by the significant beta obtained in the regression determining the path coefficient for Path 84. Evidence for an indirect effect of Experience on Scientific Reasoning through Locus of Control (P54 in Figure 4-4) would strengthen implications regarding the employ of strategies by which Experience could act upon Scientific Reasoning.

There is some theoretical speculation from Rowe (1977), that a causal relationship exists between two similar variables. Rowe implies early science experience as a determinant of fate control, as follows:

> Probably the single greatest contribution which early education in science can make to a people is the development of a sense of fate control, that is, the development of a belief based on evidence, that they can to some extent influence the direction and quality of their destiny. It is a question of fate control versus fatalism (Rowe, 1976, p. 299).

Also, the testing of Hypothesis I revealed some empirical support for a relationship, albeit non-causal by definition, between Locus of Control and Experience. A significant correlation coefficient of 0.23 ($p <= 0.004$) was obtained between Experience and Locus of Control, indicating a statistically significant amount of shared variance between the two variables.

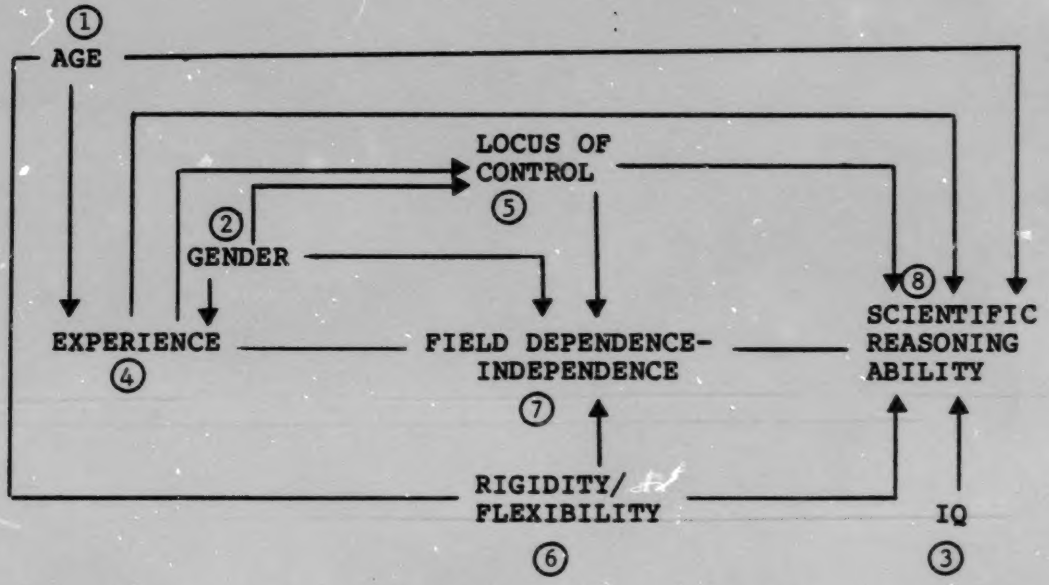

①
AGE
LOCUS OF
CONTROL
⑤
②
GENDER
EXPERIENCE
④
FIELD DEPENDENCE-
INDEPENDENCE
⑦
⑧
SCIENTIFIC
REASONING
ABILITY
RIGIDITY/
FLEXIBILITY
⑥
IQ
③

Fig. 4-4. A causal model modified post hoc to include a hypothesized relationship between Experience and Locus of Control (P54). Testing of this model resulted in no significant revisions of path coefficients.

The original model was therefore modified post hoc on the basis of a rather weak argument which relies upon (1) Rowe's statement suggesting causality between early science experience and fate control; and (2) a statistically significant correlation coefficient obtained between the two variables, not originally hypothesized, which resulted in the testing of Hypothesis I.

Pedhazur warns against the derivation of a model on the basis of weak theory, particularly in causal modeling. Being aware of the dangers in making a strong statement regarding causality, this investigator modified the causal model that was originally hypothesized on the basis of sound theory and empirical evidence to accommodate the post hoc consideration of the causal relationship of Experience as a determinant of Locus of Control. Figure 4.4 displays the exploratory, post hoc model for Scientific Reasoning which includes Experience as a determinant of Locus of Control (Path 54).

In order to test the effects of this modification, two multiple regressions were run. The first examined the effects of Gender on Locus of Control after the effects of Experience were removed. The results of that regression are summarized in Table 4-24. In this table it can be seen that the beta of 0.10 obtained for Gender, after the removal of Experience, was not significant at the set criterion of $p = 0.05$. Effects of Experience, therefore, on the relationship of Gender and Locus of Control, changed the earlier path coefficient of 0.09 only slightly.

TABLE 4-24

POST HOC MULTIPLE REGRESSION TO DETERMINE THE PATH COEFFICIENT P52 (FROM GENDER TO LOCUS OF CONTROL)

| | Beta | SE | $R^2$ | Ch.$R^2$ | T | p |
|---|---|---|---|---|---|---|
| Initial Variable Removed: | | | | | | |
| Experience | 0.14 | 0.08 | 0.02 | 0.02 | 1.84 | 0.07 |
| Path Variable: | | | | | | |
| Gender | 0.10 | 0.08 | 0.02 | 0.00 | 1.22 | 0.22 |

A second regression was run to determine the path coefficient representing the effects of Experience on Locus of Control. The results of this regression are summarized in Table 4-25. When the effects of Gender were removed, a beta of 0.15 was obtained for Experience on Locus of Control. The value of this beta was significant at 0.06, and therefore did not reach the alpha level set for significance ($p <= 0.05$).

## TABLE 4-25

## POST HOC MULTIPLE REGRESSION TO DETERMINE THE PATH COEFFICIENT P54 (FROM EXPERIENCE TO LOCUS OF CONTROL)

| | Beta | SE | $R^2$ | Ch.$R^2$ | T | p |
|---|---|---|---|---|---|---|
| Initial Variables Removed: | | | | | | |
| Gender | 0.09 | 0.08 | 0.01 | 0.01 | 1.07 | 0.29 |
| Path Variable: | | | | | | |
| Experience | 0.15 | 0.01 | 0.01 | 0.01 | 1.93 | 0.06 |

Results of this exploratory excursion were that neither path coefficient, recalculated to accommodate the addition of path P54, was significant at $p <= 0.05$. Noteworthy is evidence of the effects of shared variance between Experience and Gender, which can be observed in the results of the multiple regression used to calculate the path coefficient for Experience on Locus of Control. Once the effects of Gender on Locus of Control were removed, the resulting effect of Experience on Locus of Control was not significant.

It is concluded that inclusion of the causal relationship between Experience and Locus of Control cannot be supported by the results reported here. There is some evidence for interrelationships between Experience, Locus of Control, and Gender, but effects are not strong enough to warrant a modification of the original model.

Summary of Hypothesis III Findings

Figure 4-5 displays the revised model for Scientific Reasoning, with resulting path coefficients calculated from the simple and multiple regressions involving the remaining variables in the model displayed in Figure 4-3. This simplified model represents the results of testing the model for Scientific Reasoning postulated in Hypothesis III. The method employed in testing the model is discussed by Pedhazur (1982) as "theory trimming," a method appropriate at "exploratory stages of research" (p. 617). Initially, causal relationships within the model were postulated as a result of sound theoretical, empirical, and heuristic considerations. Paths originally hypothesized were retained or eliminated on the criterion of statistical significance ($p <= 0.05$) set for standardized beta weights obtained in the regression procedures employed to obtain path coefficients for the model. Paths not achieving the required level of significance were removed from the model. The Age-Rigidity/Flexibility path, although significant, was also eliminated on the basis that there was no evidence indicating that Rigidity/Flexibility impinged either directly or indirectly on any other variable in the model. As well, a post hoc exploration of a relationship between Experience and Locus of Control was conducted, but the results lacked significance at the level designated. Effects on Gender because of this modification were

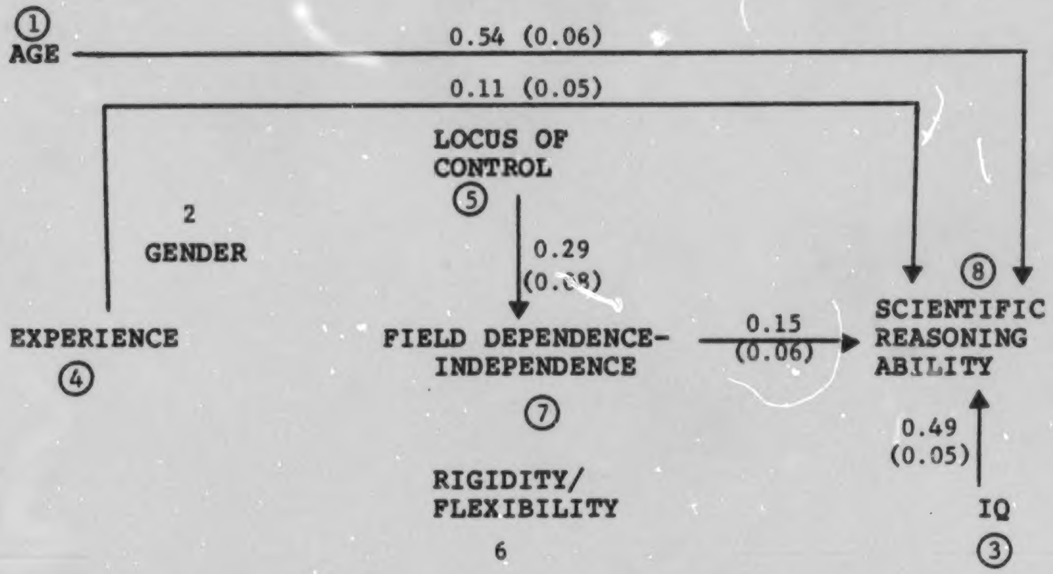

①
AGE
0.54 (0.06)
0.11 (0.05)
LOCUS OF
CONTROL
⑤
2
GENDER
0.29
(0.08)
EXPERIENCE
④
FIELD DEPENDENCE-
INDEPENDENCE
⑦
0.15
(0.06)
⑧
SCIENTIFIC
REASONING
ABILITY
0.49
(0.05)
IQ
③
RIGIDITY/
FLEXIBILITY
6

Fig. 4-5. The final revised causal model displaying significant ($p < 0.05$) relationships between variables shown to have direct and/or indirect effects on Scientific Reasoning. The path coefficients appearing in this model are the standardized beta weights obtained in regressions performed during the testing of this model.

statistically non-significant also. The "trimmed" model indicates that Scientific Reasoning is affected directly by several variables: IQ, Age, Experience, and Field Dependence-Independence. Locus of Control appears as the only indirect determinant of Scientific Reasoning, acting through the Field Dependence-Independence variable. It is on the basis of the model displayed in Figure 4-5 that conclusions, implications, and recommendations for further research were made in Chapter Five regarding the causal relationships between variables which were explored in this study.

## Summary of Results Regarding the Testing of Hypotheses I, II, and III

As a result of the testing of Hypotheses I, II, and III, different kinds of information were obtained regarding the variables under study. As a result of testing the correlational sub-hypotheses of Hypothesis I, evidence was obtained for several simple, statistically significant pairwise relationships. The correlation matrix generated as a result of testing this hypothesis revealed eight significant relationships among the variables under study. Of these, five were hypothesized and supported: Locus of Control with Field Dependence-Independence and with Scientific Reasoning; Age with Scientific Reasoning; Field Dependence-Independence with Scientific Reasoning; and IQ with Scientific Reasoning. There was evidence also obtained for three negative relationships which had been hypothesized originally to be positively correlated. These three hypotheses involved the Rigidity/Flexibility variable. Negative correlations were obtained between Rigidity/Flexibility with Age, with Field Dependence-Independence, and with Scientific Reasoning. (In Chapter Five, due to these findings, the discussion of these results examines some rethinking involving the original generation of these hypotheses.) Evidence for three other significant relationships, not hypothesized, were obtained from testing Hypothesis I. Positive correlations were obtained for Experience and Locus of Control; and for Age and IQ with Field Dependence-Independence.

Hypothesis II posited significant age group differences in the amount of explained variance shared between Scientific Reasoning with Experience, with Locus of Control, with Field Dependence-Independence, and with IQ. The results of the testing of Hypothesis II surprisingly indicated that there was no evidence to support significant differences between age groups in the relationships of these four variables to Scientific Reasoning.

Hypothesis III initially posited several direct and indirect effects of the variables under study on the ultimate dependent variable, Scientific Reasoning. The model posited in Chapter One was revised and simplified as a result of path analysis. In the revised model, shown in Figure 4-5, evidence was found for direct causal effects on Scientific Reasoning by these variables: Age, IQ, Experience, and Field Dependence-Independence. The revised path model also indicated that a causal relationship exists with Locus of Control on Field Dependence-Independence, which thereby also sets up an indirect effect of Locus of Control on Scientific Reasoning.

A summary of the significant findings regarding the testing of these hypotheses is presented in Table 4-26. These findings are explained below, variable by variable.

## Findings Regarding Experience

Hypothesis I: Hypothesized relationships of Experience with Age, with Field Dependence-Independence, with Gender, and with Scientific Reasoning were not supported. The significant correlation obtained between this variable and Locus of Control was not hypothesized.

Hypothesis II: There was no evidence to support differences between age groups in the relationship between Experience and Scientific Reasoning.

Hypothesis III: Evidence was found for a causal relationship with Experience acting as a determinant of Scientific Reasoning. In a post hoc exploration, a causal relationship between Experience and Locus of Control was tested. The resulting path coefficient was not significant.

## TABLE 4-26

## SUMMARY TABLE OF THE SIGNIFICANT RESULTS OF THE STUDY

| | Exp | Locus | Age | FDI | Rigid | IQ |
|---|---|---|---|---|---|---|
| Locus | ** | | | | | |
| Age | X | | | | | |
| FDI | X | (Sc) | ** | | | |
| Rigid | | | -- | -- | | |
| IQ | | | | ** | | |
| Sex | X | X | | X | | |
| Sci Reas | (X) | (Sc) | (Sc) | (Sc) | -- | (Sc) |

Hypothesis I: Sc = Correlation hypothesized and significance achieved
X = Correlation hypothesized but significance not achieved
** = No correlation hypothesized however significance achieved
-- = Correlation hypothesized, significant reverse relationship found when 2-tailed test applied

Hypothesis III: () = A significant path coefficient

## Findings Regarding Locus of Control

Hypothesis I: The hypothesized relationships of Locus of Control with Field Dependence-Independence and with Scientific Reasoning were supported. The hypothesized relationship between Locus of Control and Gender was not supported. A significant correlation obtained for Locus of Control with Experience was not hypothesized.

Hypothesis II: There was no evidence to support differences between age groups in the relationship of this variable with Scientific Reasoning.

Hypothesis III: Evidence was found for Locus of Control acting as a determinant of Field Dependence-Independence, and thereby indicating an indirect effect of Locus of Control on Scientific Reasoning through the Field Dependence-Independence variable. Post hoc exploration of a proposed causal relationship between Locus of Control and Experience resulted in no statistical significance.

## Findings Regarding Age

Hypothesis I: A negative correlation was obtained between this variable and Rigidity/Flexibility, although a positive correlation was originally hypothesized. This finding resulted in the rejection of this hypothesis. No support was obtained for the hypothesized relationship of Age with Experience. The significant correlation obtained for Age and Field Dependence-Independence was not hypothesized.

Hypothesis II: No age effects were found between age groups as hypothesized in relationships of Scientific Reasoning with Experience, Locus of Control, Field Dependence-Independence, or IQ.

Hypothesis III: Evidence was found for Age acting as a determinant of Scientific Reasoning. Evidence was also found for a negative effect of Age on Rigidity/Flexibility. Although the path coefficient was significant, this relationship was excluded from the revised model on the basis that no further significant causal relationships were indicated between Rigidity/Flexibility and any of the other variables impinging either directly or indirectly on Scientific Reasoning.

## Findings Regarding Field Dependence-Independence

Hypothesis I: A significant correlation was obtained between this Field Dependence-Independence and Scientific Reasoning as was hypothesized. A negative correlation was obtained between Field Dependence-Independence and Rigidity/Flexibility which resulted in the rejection of the original hypothesis concerning these two variables. The hypothesized relationship between Field Dependence-Independence and Gender was not supported. The significant correlation obtained between Field Dependence-Independence and Age was not hypothesized.

Hypothesis II: No evidence was found to support differences between age groups in the relationship of Field Dependence-Independence to Scientific Reasoning.

Hypothesis III: Evidence was found for a causal relationship with Field Dependence-Independence impinging upon Scientific Reasoning. Evidence was also obtained for Locus of Control as a determinant of Field Dependence-Independence.

## Findings Regarding Rigidity/Flexibility

Hypothesis I: Negative correlations were obtained between this variable and the variables of Age, Field Dependence-Independence, and Scientific Reasoning. All of these relationships were hypothesized to be positively correlated.

Hypothesis III: In the original hypothesized model, Rigidity/Flexibility was posited to have a causal effect on Field Dependence-Independence. As a result of path analysis, this causal relationship was not supported. The effect of Age on Rigidity/Flexibility was found to be significant in the revised model. As no evidence was found for direct or indirect effects of Rigidity/Flexibility on other variables in the model, this variable was eliminated from the model of Scientific Reasoning.

Findings Regarding IQ

Hypothesis I: A significant correlation was obtained between this variable and Field Dependence-Independence, which was not hypothesized; and between IQ and Scientific Reasoning, which was hypothesized and supported.

Hypothesis II: No evidence was found to support differences between age groups in the amount of shared variance between IQ and Scientific Reasoning.

Hypothesis III: Evidence was obtained supporting IQ as a determinant of Scientific Reasoning.

Findings Regarding Gender

Hypothesis I: No significant correlations were obtained between this variable and any other variable under investigation, although relationships were hypothesized between Gender and Experience, Gender and Locus of Control, and Gender and Field Dependence-Independence.

Hypothesis III: Although several causal relationships were originally hypothesized with Gender on Locus of Control, on Experience, and on Field Dependence-Independence, no evidence was found for causality regarding the Gender variable. As a result of these findings, Gender was excluded in the model of Scientific Reasoning.

## Findings Regarding Scientific Reasoning

Hypothesis I: Evidence was found for positive relationships between this variable and the following variables: Locus of Control, Age, Field Dependence-Independence, and IQ. Although a positive significant correlation between Rigidity/Flexibility and Scientific Reasoning was postulated, a negative correlation was obtained between these two variables, resulting in the rejection of this hypothesis. There was no evidence supporting the existence of a significant relationship, as originally hypothesized, between Scientific Reasoning and Experience.

Hypothesis II: Although significant differences were posited between age groups in the relationships of Scientific Reasoning with Experience, with Locus of Control, with Field Dependence-Independence, and with IQ, there was no evidence obtained to indicate significant age group differences.

Hypothesis III: Evidence was obtained as a result of testing the postulated model for a number of determinants acting directly on Scientific Reasoning, namely: Age, IQ, Experience, and Field Dependence-Independence. An indirect effect of Locus of Control, through Field Dependence-Independence, on Scientific Reasoning was also indicated from the results of procedures testing the paths within the hypothesized model of Scientific Reasoning.

## Summary Statement of Chapter Four

Tables 4-27, 4-28, and 4-29 summarize the significant results regarding the relationships of each of the variables to each other and to Scientific Reasoning. Only the results pertaining to the correlational hypotheses (Hypothesis I) and the testing of the hypothesized causal model (Hypothesis III) are summarized, as results of testing Hypothesis II yielded no statistically significant results.

Correlates of variables with their corresponding correlation coefficients ($r$'s, $p <= 0.004$) are presented in Table 4-27. All variables except Gender possessed significant correlates among the variables which were included in the study. Of comparative interest are the correlates of Scientific Reasoning and their corresponding correlation coefficients. Age, Field Dependence-Independence and IQ were the strongest correlates, with $r$'s of 0.57, 0.51, and 0.58, respectively. A comparatively weaker correlate of Scientific Reasoning was Locus of Control, with a correlation coefficient of 0.21. Of note is the negative correlation ($r = -0.25$) of Scientific Reasoning and Rigidity/Flexibility, which originally was hypothesized as positive. A general observation of the correlational data is that many of the variables significantly correlated with Scientific Reasoning also were correlated with each other. Shared variance between and among a number of variables in the study was thus indicated.

## TABLE 4-27

## SUMMARY OF SIGNIFICANT CORRELATIONAL DATA REGARDING ALL VARIABLES IN THE STUDY

| Variable | Correlates | $r$ | $r^2$ |
|---|---|---|---|
| Experience | Locus | 0.23 | 0.05 |
| Age | Sci Reas | 0.57 | 0.32 |
| | FDI | 0.41 | 0.17 |
| | Rig/Fx | -0.34 | 0.12 |
| IQ | Sci Reas | 0.48 | 0.23 |
| | FDI | 0.30 | 0.09 |
| FDI | Sci Reas | 0.51 | 0.26 |
| | Age | 0.41 | 0.17 |
| | IQ | 0.30 | 0.09 |
| | Locus | 0.19 | 0.04 |
| | Rig/Fx | -0.19 | 0.04 |
| Locus | Exp | 0.23 | 0.05 |
| | Sci Reas | 0.21 | 0.04 |
| | FDI | 0.19 | 0.04 |
| Rigidity/ Flexibility[a] | Age | -0.34 | 0.12 |
| | Sci Reas | -0.25 | 0.06 |
| | FDI | -0.19 | 0.04 |
| Gender | none | | |
| Scientific Reasoning | Age | 0.57 | 0.32 |
| | FDI | 0.51 | 0.26 |
| | IQ | 0.48 | 0.23 |
| | Rig/Fx | -0.25 | 0.06 |
| | Locus | 0.21 | 0.04 |
| | Experience | NS | |

---

[a] All correlations involving this variable were originally hypothesized to be positive. The negative correlations obtained resulted in the rejection of the hypotheses regarding the Rigidity/Flexibility construct. (The negative correlations obtained were significant ($p < 0.05$) when a two-tailed test was performed.)

## TABLE 4-28

### SUMMARY OF SIGNIFICANT REGRESSON DATA REGARDING VARIABLES IN THE FINAL MODEL FOR SCIENTIFIC REASONING

| Path | Sequence of Variables Removed | Beta | $R^2$ | $\Delta R^2$ |
|---|---|---|---|---|
| Age to Scientific Reasoning | FDI | 0.15 | | |
| | Exp | 0.11 | | |
| | IQ | 0.49 | 0.37 | 0.37 |
| | ---- | ---- | ---- | ---- |
| | Age | 0.54 | 0.61 | 0.24 |
| IQ to Scientific Reasoning | FDI | 0.15 | | |
| | Exp | 0.11 | | |
| | Age | 0.54 | 0.40 | 0.40 |
| | ---- | ---- | ---- | ---- |
| | IQ | 0.49 | 0.61 | 0.21 |
| FDI to Scientific Reasoning | Exp | 0.11 | | |
| | Age | 0.54 | | |
| | IQ | 0.49 | 0.60 | 0.60 |
| | ---- | ---- | ---- | ---- |
| | FDI | 0.15 | 0.61 | 0.01 |
| Experience to Scientific Reasoning | FDI | 0.16 | | |
| | IQ | 0.49 | | |
| | Age | 0.54 | 0.60 | 0.60 |
| | ---- | ---- | ---- | ---- |
| | Exp | 0.11 | 0.61 | 0.01 |
| Locus of Control to FDI | Locus | 0.29 | 0.08 | 0.08 |

## TABLE 4-29

## SIMPLE AND MULTIPLE SQUARED COEFFICIENTS OF CORRELATION FOR PATHS IN THE REVISED MODEL FOR SCIENTIFIC REASONING

| | Shared Variance | |
|---|---|---|
| Path | ($r^2$) | ($\Delta R^2$) |
| Age to Scientific Reasoning | 0.32 | 0.24 |
| IQ to Scientific Reasoning | 0.23 | 0.21 |
| FDI to Scientific Reasoning | 0.26 | 0.01 |
| Experience to Scientific Reasoning | <0.01[a] | 0.01 |
| Locus of Control to FDI | 0.04 | 0.08 |

[a] All values from which shared variance was calculated were significant at $p <= 0.004$ except this one.

As simple pairwise correlation coefficients, out of the context of path analysis, do not imply causality, interpretations from correlational data cannot be made which reflect causal relationships between variables. Interpretations of correlational data lead to conclusions regarding the magnitude and sign of the correlation between variables; and by squaring the correlation, an evaluation of the variance shared by the variables can be made. This latter statistic ($r^2$) was useful in obtaining an estimate of the maximum shared variance between variables.

Data from regressions were used in the testing and revision of a causal model for Scientific Reasoning. Regressions were initially performed to identify variables with significant path coefficients within the hypothesized causal model. All variables originally included in the model except Gender and Rigidity/Flexibility were found to have either direct or indirect causal effects on Scientific Reasoning. The model was simplified on the basis of these results to include the variables listed in Table 4-28. Regressions were then performed on variables in the simplified model to obtain path coefficients (listed as beta values in Table 4-28) for the paths between variables in the simplified model. Of those variables affecting Scientific Reasoning directly, the strongest standardized path coefficient obtained was for Age, with a beta value of 0.54. IQ was also a strong determinant, with a resulting beta value of 0.49. Weak determinants of Scientific Reasoning were Field Dependence-Independence and Experience, with standardized betas of 0.15 and 0.11, respectively. Evidence for the indirect effect of Locus of Control on Scientific Reasoning was indicated by the calculated path coefficient of 0.29 between Locus of Control and Field Dependence-Independence.

The testing of Hypotheses I and III also resulted in information regarding shared variance between pairs of variables. Table 4-29 presents values for shared variance calculated from correlations ($\underline{r}^2$) and from regression techniques ($\Delta R^2$). Shared variance was calculated from correlations by squaring the correlation coefficient (Table

4-27). Shared variance was calculated from regression data by evaluating the change in $R^2$ indicated in the last column of Table 4-28. In multiple regression, an overall $R^2$ was obtained from the results of the regression analysis which indicates the amount of variance in Scientific Reasoning which was explained by the variables in the regression equation. That value for explained variance in the overall model was 61%. Change in $R^2$ indicated the change in the variance explained by the addition of the particular variable entered last. Interpretive significance of the two calculations for shared variance differs. The simple $r^2$ indicates shared variance between variables which may not be exclusively shared by the two variables. (In the present study, this situation was indeed likely, as many significant correlations were obtained between variables). The change in $R^2$, on the other hand, indicated additional variance in the dependent variable attributed to the added variable, devoid of variance in the dependent variable shared by other variables in the equation. With this understanding, the amounts of shared variance indicated by the two methods were compared.

Relatively high calculations for shared variance were obtained by correlational (32%) and regression techniques (24%) for the Age variable and Scientific Reasoning. A difference in these values indicates that around 8% of the variance shared as calculated by $R^2$ is variance which is commonly shared by Age and Scientific Reasoning with other variables in the model. Regarding the relationship of IQ and Scientific Reasoning, the very similar calculations of 23% and 21% indicate shared variance which is relatively uncontaminated by other variables in the model.

The comparison of the squared value of Pearson's $r$ and change in $R^2$ for Field Dependence-Independence and Scientific Reasoning, however, led to different conclusions regarding the relationship between Field Dependence-Independence and Scientific Reasoning. The 26% shared variance between Field Dependence-Independence and Scientific Reasoning, as indicated by correlational calculations, was reduced to 1% in the regression analysis. Most of the shared variance indicated by the squared Pearson's $r$ was therefore interpreted as being shared with other sources. Possible contaminants, as indicated by significant correlations with both Field Dependence-Independence and Scientific Reasoning are Age, IQ, Locus of Control, and Rigidity/Flexibility. The regressions performed to test the causal model did not hypothesize all of these relationships to Field Dependence-Independence and Scientific Reasoning as causal; therefore, a better accounting of the shared variance was not available. It can be generally concluded that the comparisons indicate that variance implied to be shared between the two variables by the correlational data is contaminated with other variance.

It may also be concluded that Field Dependence-Independence is a weak contributor to the overall variance explained by the variables included in the model for Scientific Reasoning.

Comparatively simple results were obtained from calculations of shared variance by the two methods for the relationship of Experience to Scientific Reasoning. Regression methods indicated a change of 1% in amount of variance explained by the addition of Experience to the regression equation for Scientific Reasoning. A statistically insignificant correlation coefficient obtained between the two variables indicates little or no relationship on the basis of correlational data. It therefore my be concluded that statistical evidence points to a relatively small change in explained variance due to Experience in the overall model of Scientific Reasoning. The amount of shared variance between Locus of Control and Field Dependence-Independence has been calculated as 4% on the basis of correlational data and 8% on the basis of regression analysis. The methods therefore indicate no conflictual results in the comparison. It may be concluded that the shared variance between Locus of Control and Field Dependence-Independence, as indicated by the regression, is the more accurate measure of shared variance, as variance caluclated by squaring correlation coefficients is known to be a conservative estimate (see Fox, 1969).

# CHAPTER FIVE

## DISCUSSION OF THE RESULTS: CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

This research sought to elucidate information that would be of theoretical and practical use in broadening our understanding of scientific reasoning ability in adolescents. The aim was to contribute to the fields of science education and educational psychology by (1) formulating a model for the relationship of relevant variables in predicting scientific reasoning; (2) lending support to the prior evidence indicating the link between certain variables broadly characterized as individual differences and the particular cognitive ability referred to as scientific reasoning; and (3) providing a theoretical framework for further research studies to examine the effects of interventions on the development of scientific reasoning in individuals possessing particular aptitudes and/or other personological traits. It is the purpose of this chapter to discuss the results of the research as outlined in Chapter Four; to draw conclusions from these results; to examine the implications of those results; to recommend further directions for study as suggested by questions arising from the results of the research; and to generally evaluate the research in terms of how much and what kinds of information were elicited as a result of this particular enterprise.

In format, this chapter is similar to that of Chapter Two, where a major portion of the chapter deals with each variable separately. Section I of this chapter includes a variable-by-variable discussion of the results of the research, including a general review of the particular variables; a discussion of the results of the hypothesis testing procedures; conclusions regarding these results; theoretical and educational implications of the results; and recommendations regarding further study of the variable. Section II presents a general synthesis of these comments, with a particular emphasis on the contributions of this research effort to the field of science education. Included within this section are discussions dealing with the Conclusions of the Research, the Implications of the Research, and the Recommendations for Further Study.

## Section I. Discussion, Conclusions, Implications, and RecommendationsRegardingIndividual Variables Examined Within the Research

### Philosophical Basis of the Research

Prior to the discussions of the individual variables which were examined within the research, a brief review is presented of the philosophical base from which the research was designed. Reviewed in particular are those aspects of the theoretical foundation which are referenced later in discussions regarding conclusions, implications and recommendations for further research.

A model of human functioning based upon exploration and self-actualization was used as a theoretical foundation for this study. This model was fashioned from the philosophies of Mooney, Maslow, and Rogers. In this model, rationality was theorized to develop naturally as a function of unrestricted human experiencing with the passage of time. Concurring with this model are the philosophies of Bronowski and Cohen regarding the nature of science, and the theory of Piaget concerning human cognitive development. A conclusion underlying the present research was the conceptualization of scientific thought as a precise extention of self-actualizing man's natural posture. On the basis of this conclusion, potential determinants of Scientific Reasoning were identified for further study. Hypotheses were then developed regarding the determinants of Experience, Locus of Control, Age, Field Dependence-Independence, Rigidity/Flexibility, IQ, and Gender as they related to the development of Scientific Reasoning in adolescents. The first of these hypotheses dealt with a number of relationships between the variables themselves and between particular variables and Scientific Reasoning. On the Piagetian premise of the importance of age in the development of logical thinking schemata, Hypothesis II was generated. In this hypothesis, age effects were predicted to affect the relationships of a number of variables with scientific reasoning ability. Finally, a model was formulated in Hypothesis III on the basis of prior research and theoretical considerations which explained causally the direct and indirect effects of predictors upon scientific reasoning ability. It is on the basis of the information acquired from the testing of these three hypotheses that Chapter Five is written.

The results of the analyses performed in testing Hypotheses I, II, and III, their conclusions, implications, and recommendations regarding the separate variables are discussed within this section. For each variable, five aspects of the research are included. Initially, a review of key information pertaining to the variable is provided. The hypotheses and the results of hypothesis testing relating to the variable are discussed. Conclusions regarding the results are made. Theoretical and educational implications of the research are discussed. Finally, recommendations regarding further research which came as a result of the present findings concerning the particular variable are made. Following are separate discussions pertaining to each of these variables: Experience, Locus of Control, Age, Field Dependence-Independence, Rigidity/Flexibility, IQ, and Gender.

## A. Experience

### Overview of the Variable

Out of the philosophical framework constructed for the present research, Experience was identified as a key component in the development of human cognitive abilities, which include those identified specifically as scientific reasoning abilities. Previous research in the field of cognitive development suggested that particular sorts of experiences, e.g., those requiring the active manipulation of concrete objects and active mental restructuring, appeared to influence the development of logical thought schemata and ultimately the development of formal operational thought. In the present research, a set of activities very similar to those suggested in earlier research were identified in the present research by a number of science educators. These educators were asked to rate experiences common to adolescents as to their strength in contributing to the development of reasoning in adolescents. The measure used as the Experience variable in the present research was a scale developed by the author from the responses of these educators, designed to determine the extent to which adolescents engaged in actitives which had been identified as contributing to the developmeent of adolescent reasoning.

## Discussion of Hypotheses

In Hypothesis I, Experience was hypothesized to be directly correlated with both Scientific Reasoning Ability and Field Dependence-Independence. The possible correlation of Field Dependence-Independence and Experience was identified in large measure due to previous research reports which included conjectures that certain types of experiences probably contribute to the development of spatial visualization abilities such as those employed by persons characterized as being field independent. Experiences listed in these reports (e.g., Kahle, 1983; Sherman, 1967; Tanner and Inhelder, 1958) were often identical to those identified as contributing to Scientific Reasoning Ability.

In Hypothesis II, it was hypothesized that there would be Age Effects associated with the amounts of shared variance between Experience and Scientific Reasoning. Philosophical framework, heuristic considerations, and Piagetian theory which emphasizes the importance of age in experiencing the environment were employed in the generation of this hypothesis.

The causal model of Hypothesis III posited that Experience has a direct effect on Scientific Reasoning as well as an indirect effect on Scientific Reasoning through Field Dependence-Independence. The indirect effect of Experience on Scientific Reasoning was hypothesized as a result of strong evidence in the literature supporting a relationship between Scientific Reasoning and Field Dependence-Independence. (A review of this literature is provided in Chapter Two and will be summarized in this section in the discussion pertaining to the Field Dependence-Independence variable.)

## Discussion of Results

Results of testing the three hypotheses were that Experience was not significantly correlated with either Field Dependence-Independence or Scientific Reasoning Ability (Hypothesis I); that there were no significant age differences in terms of explained shared variance between Experience and Scientific Reasoning Ability (Hypothesis II); and that there was evidence for the direct effects of Experience on Scientific Reasoning Ability, but no evidence for effects through Field Dependence-Independence as hypothesized in the causal model (Hypothesis III).

Several reasons for the apparent lack of support regarding the hypothesized correlational relationships can be suggested. Perhaps the Experience variable was too narrowly defined; in terms of the philosophical foundation of the research, more general types of experiences in real-life problem-solving could have been included in the Cognitive and Recreational Activity Scale. Several activities included within the initial check-list, presented to educators in the development of this scale, suggested more general types of experiences (e.g., baby-sitting, earning money, family discussions of politics), but were excluded because of their low ranks. Perhaps the scale should have included the lower-ranked activities. Results of the study by DeCarlo (1974) also suggest a reinterpretation of the Experience variable. In DeCarlo's examination of factors affecting the successful aging of octogenarians, "intellectual exercise" was identified as a characteristic of individuals who fared better in terms of sustained cognitive abilities and therefore generalized "successful ageing."

For the relationship between Field Dependence-Independence and Experience, the employ of a conservative alpha level ($p <= 0.004$) for the testing of Hypothesis I resulted in the lack of significance.

It is also pertinent to remember that the hypotheses involving the Experience variable were based primarily upon suggestions (rather than evidence) from a number of researchers working in the field of cognitive development. Empirical evidence from previous research supporting the relationship of Experience as defined in the present research and its hypothesized correlates is scanty and often non-existent. It is therefore not totally surprising that the present research does not support previous conjecture regarding these relationships.

Although not hypothesized, a significant correlation ($r = 0.23$, $p. <= 0.004$) between Experience and Locus of Control was obtained when the correlation matrix was generated in testing Hypothesis I. As the review of previous research involving the Locus of Control construct did not suggest such a relationship, it was not hypothesized that Experience, particularly as defined within the limits of the Cognitive and Recreational Activity Scale, would correlate with the Locus of Control construct. An exploration of causality in the post hoc modification of the original model resulted in no significance for the postulated relationship of Experience as a determinant of Locus of Control. The results of testing Hypothesis II, i.e., no significant differences between age groups in amounts of shared variance between Experience and Scientific Reasoning, may be explained in two ways. First, there is the possible problem in the construction of the scale measuring Experience, which was discussed previously. Also possible is the choice of subjects in comparing age groups; perhaps if groups farther apart in age had been compared, the differences expected in younger and older samples concerning the relationship of Experience to Scientific Reasoning would have been realized.

The results of the testing of the causal model indicate a causal relationship between Experience and Scientific Reasoning which, although statistically significant, has relatively limited educational significance. The contribution of Experience to the model of Scientific Reasoning, as summarized in Table 4-18, is small. Variance accounted for in the regression, indicated by the $R^2$ value in this table, is 60%. The addition of Experience increased the amount of explained variance by 1% (i.e., to a total of 61%), significant at the $p < 0.01$ level.

## Conclusions

If the findings had confirmed Experience as a strong determinant of Scientific Reasoning, the conclusion could have been firmly stated that that adolescents higher in Scientific Reasoning are those who engage in activities which have been identified as requiring active manipulation of concrete objects (e.g., sculpture, carpentry, programming a computer) and/or high levels of abstraction void of concrete manipulations (e.g., solving word problems in math, writing poetry, doing geometry problems). Strong evidence for this relationship would have concurred with Piagetian theory regarding general cognitive development: that the development of reasoning in the child is based in experience of two kinds, physical experience, leading to the development of mental structures about objects; and logico-mathematical experience, which leads to the development of mental structures which by the time of adolescence enable one to abstract, think about thought, and to reason propositionally (Inhelder and Piaget, 1958).

The findings, however, indicate very small effects of Experience, as defined by the Cognitive and Recreational Activity Scale, on Scientific Reasoning.

## Implications

The findings regarding the effects of Experience on Scientific Reasoning indicate only slightly that the particular kinds of experiences listed in the Cognitive and Recreational Activity Scale enhance the development of scientific reasoning abilities. With stronger results to support the experiential link with Scientific Reasoning, science curricula could have been suggested to enhance reasoning which stress actual manipulation of concrete objects, beginning at early pre-adolescent stages and continuing throughout adolescence, should lead to the acquisition of physical knowledge regarding properties of objects and their actions in the environment, as described by Piaget and Kamii. Open-ended inquiry would also be implicated as a means to effect the development of logico-mathematical knowledge (Karplus, 1979).

## Recommendations

Because of the strong educational implications regarding the ultimate effects of this variable on Scientific Reasoning, a closer examination of the Experience component is suggested. In this regard, a broader definition of the Experience variable may be warranted.

Included within this redefinition would be experiences which include more general forms of intellectual involvement. As a result of the redefinition of this variable, age effects, which were originally expected, may become evident.

In terms of the correlation of Locus of Control with Experience, which was not originally hypothesized, further exploration of this relationship is also suggested. Rowe (1976) surmises that Experience, in the form of "early education in science" (p. 299) may be the "single greatest contribution ... to a people" in the development of "fate control" (i.e., locus of control). Even though the results of the post hoc attempts to modify the hypothesized model for Scientific Reasoning did not indicate significance for the causality of Experience acting upon Locus of Control, further examination of this relationship may result in evidence to support Rowe's speculations. The results of the finding that Locus of Control affects Field Dependence-Independence encourages further exploration of the Locus of Control-Experience relationship. As Locus of Control indirectly affects Scientific Reasoning because of its relationship to Field Dependence-Independence, evidence that a causal relationship exists between Experience and Locus of Control would reveal another pathway through which Scientific Reasoning can be influenced. That is, Experience can affect Locus of Control which can in turn affect Field Dependence-Independence and ultimately Scientific Reasoning.

## B. Locus of Control

### Overview of the Variable

The premise that there are social elements which affect the general development of cognitive abilities was discussed in Chapter Two. Locus of control was chosen as the construct in this research to represent the social effects contributing to the development of scientific reasoning abilities. The rationale for this choice is presented in Chapter One. The term "locus of control" refers to the generalized expectancy for reward which an individual consistently demonstrates; i.e., externals indicate that they expect rewards from significant others and attribute the consequences of their actions to fact; and internals demonstrate that their expected source of reward is internal, attributing the consequences of their actions to their own personal sources. It has generally been conjectured that internals would employ mental strategies different from those of externals in anxiety- or stress-producing situations, such as those arising in unfamiliar situations. In such situations, the internal has been characterized (Phares, 1976) as preferring to be the actor rather than the pawn, and in so doing, engages in active, cognitive processing. As scientific reasoning also involves active cognitive processing, it was hypothesized within the present research that the development of scientific reasoning would be influenced by locus of control, and that internals, as the more active cognitive processors, would be better scientific reasoners. There is also active cognitive processing in the spatial visualization abilities of field-independent persons. On this basis, an association of field independence and internal locus of control was also hypothesized.

## Discussion of Hypotheses

More specifically, within the present research, Hypothesis I posited significant relationships of Locus of Control with both Field Dependence-Independence and Scientific Reasoning. The effects of Locus of Control on Scientific Reasoning were hypothesized to increase with age (Hypothesis II). Finally, incorporated into the model of Hypothesis III were the direct effects of Locus of Control on Scientific Reasoning and on Field Dependence-Independence. An indirect effect of Locus of Control on Scientific Reasoning was also postulated as a result of the hypothesized effects of Field Dependence-Independence on Scientific Reasoning Ability.

## Discussion of Results

Locus of Control showed significant correlations of similar strengths (*r*'s of 0.19 and 0.21) with Field Dependence-Independence and Scientific Reasoning, respectively. Locus of Control was found also to be significantly correlated with Experience, even though this relationship was not initially hypothesized. A review of previous research did not provide empirical evidence upon which to hypothesize a causal relationship, and this relationship was therefore not included in the causal model of Hypothesis III.

As a result of the testing of Hypothesis II, no evidence was obtained to support the hypothesized age group differences in the relationship of Locus of Control and Scientific Reasoning. This finding indicated that the strengths of association between social effects and scientific reasoning ability were not significantly different in the samples of younger and older adolescents. It is speculated that differences due to social effects may be more apparent when the range is extended between the older adolescent sample and younger sample. Some of the research in gender differences (e.g., Petersen and Wittig, 1979; Sherman, 1967; Treagust, 1980) indicates that a between groups difference should exist.

When the causal model of Hypothesis III was tested, evidence for a causal relationship with Locus of Control on Field Dependence-Independence was obtained. There was no evidence to support a direct effect of Locus of Control on Scientific Reasoning, however. The simple regression performed on Locus of Control to Field Dependence-Independence resulted in an obtained path coefficient of 0.28 for that path (Table 4-22). As well, the regression indicated that the amount of variance in Field Dependence-Independence explained by Locus of Control was 8%, which was statistically significant (p <0.01). The relationship between Locus of Control and Field Dependence-Independence also indicates an indirect effect of Locus of Control on Scientific Reasoning through the Field Dependence-Independence variable.

## Conclusions

Evidence from these findings indicate the importance of Locus of Control within the model for Scientific Reasoning as an indirect determinant of Scientific Reasoning through the Field Dependence-Independence variable. In the final revised model for Scientific Reasoning, no other variable was indicated as impinging upon Field Dependence-Independence. Educational implications for Field Dependence-Independence in the model for Scientific Reasoning are considerably widened as a result of the connection with Locus of Control. Of the three other variables found to impinge directly upon Scientific Reasoning (i.e., Age, IQ, and Experience), only Experience can be manipulated to effect change in Scientific Reasoning. Therefore, Locus of Control gains importance in the model as another manipulatable variable.

## Implications

The causal path involving Locus of Control - Field Dependence - Scientific Reasoning suggests several educational implications. One implication is in terms of the differential implementation of rewards by teachers to students on the basis of the student's perceived expectancy for reward. Rowe (1976) suggests in general that overt verbal rewards by teachers are regarded differently by students who are extrinsically rather than intrinsically motivated. Rowe quotes research by Locke, who suggested that when external rewards are congruent with the intention of a person, they may act to sustain high levels of performance; and that when rewards are not appropriately matched there is no facilitative effect of rewards. Sometimes, in fact, there may be even negative consequences (Rowe, 1976). In terms of motivating students engaging in the study of physical and biological systems, Rowe suggests that the curriculum itself may be intrinsically interesting and that extrinsic rewards administered by a teacher during an investigation may produce a conflict in students who intrinsically reward themselves.

The present research has indicated that individuals displaying an internal locus of control have higher abilities in scientific reasoning, through the mediation of field dependence-independence. In other words, the reinforcement expectations for field-independents is most likely intrinsic. This finding is supported by previous work of Witkin et al. (1977). An implication for sustaining and/or enhancing the active cognitive processing of the field-independent, therefore, would be to exclude overt verbal rewards from the repertoire of teacher behaviors.

Conversely, externals were shown in the present research to have significantly lower abilities in spatial visualization, i.e., they were field dependent. This finding may be interpreted by saying that, even though in some instances external rewards may facilitate high levels of performance (Rowe, 1976), a high degree of development in active cognitive processing such as should involved in spatial visualization and scientific reasoning is not to be expected in external individuals. If one is indeed interested in developing scientific reasoning abilities in externals, a conversion in locus of control should most likely be considered.

Rowe explores some possibilities as to how to effectively convert externals to internals. Early experiences in science are one suggestion. (In terms of the model posited for this research, "early experiences in science" would be ones which provide for direct manipulation of concrete objects and spatial visualization activities.)

> Probably the single greatest contribution which early education in science can make to a people is the development of a sense of fate control, that is, the development of a belief based on evidence, that they

> can to some extent influence the direction and quality of their destiny. It is a question of fate control versus fatalism. (Rowe, 1976, p. 299)

Another suggestion is that efforts be made to assure consistency and lack of ambiguity in teacher reward patterns. Rowe's data suggested that teacher reward patterns which are ambiguous and administered differentially without a clear relation between student input and output may contribute to the development of externality in students, particularly in students ranked at the bottom of the group.

Still another suggestion by Rowe (1976) is to consider other traits which characterize students low in fate control, a set of which has been termed "secondary ignorance" by Sieber. Secondary ignorance is a term used to characterize students who consistently do not recognize that they do not know--arriving at solutions rapidly, incorrectly, and with certainty of their correctness.

> There is some possibility that students classified as high impulsives may be low on fate control, may have lived under a regimen of strong sanctioning from external sources and been required to respond on short wait time schedules. (Rowe, 1976, p. 306)

On the basis of this speculation, Rowe suggests these methods: (1) teaching students to take time to think; (2) creating simple situations in which alternative answers are plausible; and (3) demonstrating that it is appropriate to be uncertain about inferences. Group process facilitation is also suggested by Rowe as a way to channel thedecisionmaking away from teachers and towards students. Students involved in group decision-making are faced with organizational problems and interdependence stresses which are often driven by argument and conceptual conflict.

> It is in talking about what we have done and observed and in arguing about what we make of our experiences that ideas multiply, become refined, and finally eventuate in new questions and experiments. (Rowe, 1976, p. 293)

The present research suggests that once the students are involved in active cognitive processing such as that described by Rowe, the enhancement of field independence should also be expected. If the model is correct, then scientific reasoning abilities ultimately should be enhanced.

## Recommendations

It is strongly recommended that the link between Experience and Locus of Control be examined more closely. Logically, one could build an argument for the association of internals with experiences which are more independent, solitary, and intrinsically rewarding. Conversely, Rowe's speculations would tend to support particular experiences as quite important determinants in the development of an internal locus of control. Empirical evidence is needed to support either argument. The post hoc exploration of this relationship in the present study did not provide statistically significant evidence. Well-planned research designed to test a priori hypotheses is suggested in order to determine whether a causal relationship does indeed exist between the two variables, as well as to determine the direction of the relationship.

Also intriguing is the question of interventions effective in changing the locus of control of an individual. Rowe indicates that a change is possible in the school setting. If so, identification of strategies which may effect this change is needed. Carefully designed studies which aim to examine the interactive effects of Locus of Control and treatments such as teacher reinforcement, early science experience, wait time, the inquiry approach, and group process facilitiation (as suggested by Rowe, 1976), would definitely have implications for individualizing instruction to maximize outcomes such as the acquisition of scientific reasoning abilities.

## C. Age

### Overview of the Variable

Integral to the Piagetian model of cognitive development, which forms part of the theoretical framework used for the present research, is the variable which Piaget often referred to as "maturation." The measure of maturation chosen for the present study was chronological age. In Piagetian research other measures have either been suggested or actually used, such as brain growth (Bybee and Sund, 1982; Epstein, 1974a, 1974b), "working memory" (Case, 1975, 1979); and grade level (Lawson and Renner, 1974). However, there are as many or more studies which also used the simple measure of chronological age (e.g., Lawson and Renner, 1974; Lawson, 1978; Rowell and Hoffmann, 1975).

Hypotheses were formulated regarding the Age variable: correlates of Age (Hypothesis I); differences in the amount of shared variance between variables and Scientific Reasoning in the two age groups of adolescents sampled (Hypothesis II); and the causal effects of Age on other variables in the hypothesized model of Scientific Reasoning which was developed for testing, ultimate revision and simplification (Hypothesis III).

### Discussion of Hypotheses

Hypothesized as correlates of Age (Hypothesis I) were the following variables: Experience, Rigidity/Flexibility, and Scientific Reasoning. Regarding age group differences (Hypothesis II), several variables and their relationship to Scientific Reasoning were hypothesized to be significantly different between the younger and older adolescent samples. And in the causal model (Hypothesis III), Age was hypothesized to have a causal effect on Rigidity/Flexibility, Experience, and Scientific Reasoning.

### Discussion of Results

The findings regarding the Age variable indicated that a significant correlation did not exist with the Experience variable as hypothesized. It was suggested in the previous section on Experience that perhaps the restriction of the Experience variable in the design of the Cognitive and Recreational Activity Scale led to a lack of strength in the ability of this instrument to measure the Experience variable. Age was found to be positively correlated with Scientific Reasoning, however, a finding which is consistent with the Piagetian model for cognitive development and the literature cited in Chapter Two. A negative correlation was obtained for the Age-Rigidity/Flexibility relationship, which was not expected. The reasoning for the hypothesized positive correlation was based upon an interpretation of Mooney's model for full functioning that as the individual grows in age and experiences more in his environment, he becomes more flexible in dealing with situations unlike those previously experienced. However, it may also be reasoned that time is needed for the relatively free, unstructured, flexible child to develop more structured, disciplined thought patterns. On the basis of all findings regarding the Rigidity/Flexibility variable, the latter interpretation is probably more appropriate. This idea is explored further in the section dealing specifically with the Rigidity/Flexibility variable. Also as a result of the correlation matrix which was generated in testing the subhypotheses of Hypothesis I, Age was found to be positively correlated with Field Dependence-Independence. This relationship was not originally hypothesized. Witkin et at. (1977) discuss the changes which occur in Field Dependence-Independence over age, stating that the variable becomes fixed around the age of 17. However, on the basis of studies dealing with the Field Dependence-Independence construct, a strong experential rather than maturational effect was expected concerning the eventual determinant of the Field Dependence-Independence variable. The relationship therefore was not pursued further in the development of the causal model.

The results of testing the four subhypotheses of Hypothesis II revealed no significant differences. Differences in shared variances between the two age groups on a number of variables (IQ, Field Dependence-Independence, Locus of Control, and Experience) and Scientific Reasoning were not significant. Initially, hypotheses regarding these differences in relationships between variables were based upon the notion that precocity, in the form of IQ, would have a stronger relationship with Scientific Reasoning in younger adolescents than in older adolescents. It was also posited that the sample of younger adolescents would indicate a significantly stronger relationship of Locus of Control with Scientific Reasoning than in the sample of older adolescents. In other words, it was reasoned that IQ and Locus of Control would be stronger predictors of Scientific Reasoning in the younger sample. In the other two sub-hypotheses, shared variance between Scientific Reasoning and Field Dependence-Independence (as an "aptitude" variable) and between Scientific Reasoning and Experience was expected to be greater in the older adolescent group. In the development of these hypotheses, it was reasoned that the effects of both variables on Scientific Reasoning would be significantly more evident in the older sample as a result of changes occurring during adolescence, rather than on the earlier social effects of Locus of Control or the effects of precocity as indicated by an IQ score. Alpha levels obtained for the four sub-hypotheses of Hypothesis II were not significant at a level which warranted acceptance. These results do not indicate that differences in age groups can be detected by comparing amounts of shared variance between Scientific Reasoning and any of the four variables examined: IQ, Locus of Control, Field Dependence-Independence, or Experience.

Age was originally hypothesized in the causal model of Hypothesis III to be a determinant of Rigidity/Flexibility, Experience, and Scientific Reasoning. The testing of this model resulted in the revision of the model (Figure 4-3) to include only a direct effect of Age on Scientific Reasoning. Even though a path coefficient of -0.32 was obtained for the effects of Age on Rigidity/Flexibility (Table 4-8), this relationship was excluded in the final model on additional findings that Rigidity/Flexibility neither directly nor indirectly influenced Scientific Reasoning. The effects of Age on Experience, summarized in Table 4-7, indicated no significant relationship between the two variables: a beta of -0.01; and no contribution of Age to the amount of explained variance in the Experience variable. In examining other results, the Experience variable was again questioned, this time in light of the capability of this instrument to detect differences in experiences producing changes in Scientific Reasoning as a result of age. In examining the effects of Age on Scientific Reasoning, a path coefficient of 0.54 indicated a significant causal relationship between the variables. In the multiple regression performed to obtain this path coefficient, the amount of variance before the addition of Age explained by the model was 37% (due to the effects of Field Dependence-Independence, Experience, and IQ). The addition of Age contributed 24% in terms of explained variance, so that the overall variance explained by all variables included within the final model of Scientific Reasoning was 61%.

## Conclusions

On the basis of these findings, it was concluded that Age is a direct determinant of Scientific Reasoning. The results of this study indicated that one can generally expect older adolescents to display better scientific reasoning abilities than younger adolescents. There is also evidence to support the heterogeneity of both adolescent groups, however, so that it can also be expected that within younger and older adolescent samples there will be a range from low to high abilities in scientific reasoning. These results concur with previous expectations, as discussed by Karplus (1979).

> Past investigations of student reasoning by Piaget, his collaborators, and many others have documented a gradual development that can provide a teacher with rough statistical guidelines about the distribution of abilities to expect in a group of students of a certain age. Thus, preschool and primary grade children would usually apply reasoning patterns at the concrete level or not at all. Pupils in the middle and upper grades would apply reasoning patterns predominantly at the concrete level, with some gaps in application and occasional applications showing formal level reasoning. .... The gradual shift of the use of reasoning patterns from the concrete level to more advanced ranges of the continuum is extended for high school and college students, but few individuals have been found to apply many different reasoning patterns consistently at the formal level. Perhaps the principal significance of this brief survey of the development of reasoning is that every teacher must expect a diversity of

> approaches by his or her students and by the same student on different occasions. [underline added for emphasis] (Karplus, 1979, p. 158)

## Implications

Implications for education in reasoning are detailed by Karplus (1979) in the review entitled "Teaching for the Development of Reasoning." In this review, Karplus describes the level and progress of reasoning of individual students in terms of reasoning patterns, defined as "identifiable and reproducible thought process directed at a type of task" (Karplus, 1979, p. 151). A detailed list is provided to teachers in the identification and subsequent applications of reasoning patterns, which Karplus suggests are continuous in their development from early childhood to adulthood. Although continuous, the terms "concrete" and "formal" level reasoning are used by Karplus as ranges on the continuum of reasoning patterns. Concrete level reasoning is characterized as being direct, dealing with observable and familiar conditions, and making use of simple relationships. (Students in the present study who scored low on the Scientific Reasoning Test would fall on the concrete side of the reasoning continuum.) Formal level reasoning, on the other end of the continuum, copes with tasks that require an indirect approach, dealing with the abstract, not directly observable properties, idealizations, limiting processes, and hypotheses contrary to reality.

Given that students within any age group fall between the two extremes, Karplus suggests approaches which take into account these differences in reasoning and thereby address the individual needs of students in the classroom which are based upon the different reasoning patterns which are exhibited. Specific implications which are discussed below address these suggestions:

> First, educational subject matter and assignments should be matched to students' reasoning; second, teaching should be concerned with the reasoning that students engage in; third, the formation of new reasoning patterns should be important instructional objectives. (Karplus, 1979, p. 155)

Karplus stresses the point that most important for the implementation of any strategy is a commitment by educators to the development of reasoning in addition to the usual concern for content. A model for Scientific Reasoning which indicates that reasoning abilities advance with students' age along a continuum from "concrete" to "formal reasoning patterns," that certain general expectations regarding reasoning can be made regarding the age level being taught, and that a classroom at any grade level will be heterogeneous in terms of reasoning abilities suggests that individualizing science instruction may best meet the needs of students in the science classroom. Evaluation of concepts, assessment of students' level of reasoning patterns, modification of instruction to reflect the learning cycle, adoption of curricula which are laboratory based and inquiry oriented, and alteration of teachers' behaviors are some approaches which have been suggested as ways in which to enhance reasoning in students of all ages with varying reasoning abilities.

## Recommendations

A first recommendation concerns the theoretical framework upon which the differences in age groups were hypothesized. The findings of the present research indicate that there are no significant differences in younger and older adolescents in the amounts of shared variance between Scientific Reasoning and any of the variables originally hypothesized. An inability to detect differences in age groups as a result of instrumentation problems (i.e., in the choice of activities for the Cognitive and Recreational Activity Scale), has been discussed previously. Intuitively, the researcher, who has spent eight years working with adolescents, suspects that differences should exist. It is therefore recommended that the exploration of the differences in middle school and high school students in Scientific Reasoning should be pursued in order to identify variables which effect change and differentiate abilities in Scientific Reasoning during the adolescent years of development. Examination of the effects of the Experience variable, defined in terms of laboratory-based and inquiry-oriented curriculum exposure, on the development of scientific reasoning is also recommended. Long-range studies are suggested which examine the interactive effects of age with a number of variables, with age, in the development of scientific reasoning.

## D. Field Dependence-Independence

### Overview of the Variable

One of the factors discussed by Piaget (1972) as affecting the acquisition of formal operational thought in adolescents was "aptitude." Aptitude for formal thinking was discussed in general terms, however, and no specific suggestion was made by Piaget as to a particular personological variable which might affect the development of logical thinking in adolescents. In the course of preparing for the present research, several variables were considered which might have qualified as an aptitude for scientific reasoning. Most evidence found in the literature (e.g., Adi and Pulos, 1980; Crandall and Lacey, 1972; Kahle, 1983; Kamii, 1973; Niemark, 1979) suggested that high spatial ability, understood to be quite similar to, if not the same as, Witkin's construct of field independence, was the most likely "aptitude" to act upon the development of scientific reasoning in adolescents. Witkin et al. (1977) compared various tasks used to measure the construct of field dependence-independence, and concluded that

> The common denominator underlying individual differences in performance in these various tasks is the extent to which the person perceives part of a field as discrete from the surrounding field as a whole, rather than embedded in the field; or the extent to which the organization of the prevailing field determines perception of its components; or to put it in everyday terminology, the extent to which the person perceives analytically (Witkin et al., 1977, pp. 6-7).

The question then became one of the origin of tendencies towards field independence. A review of previous research pointed to a number of possible determinants of field independence. Perhaps implicated most strongly was Experience, and in particular, experiences requiring logico-mathematical and/or physical manipulations upon objects (Kamii, 1973; Kahle, 1983; Sherman, 1967), such as those measured in the Cognitive and Recreational Activity Scale developed for this research.

Frequent mention was found in the literature of gender differences in field dependence-independence, leading to the choice of Gender as another probable determinant of Field Dependence-Independence. Sherman, Kamii, and Kahle made note of the differential exposure of boys and girls to particular experiences affecting the development of field independence, speculating that males have more opportunities to develop their spatial abilities as a result of in-school and out-of-school activities. Other authors (e.g., Inhelder in Sherman, 1967; Treagust, 1980) tended to adopt a genetic/developmental explanation for the tendency of males to be field independent, citing evidence that with the onset of puberty, males showed stronger tendencies towards field indepedence.

Evidence can also be found to support the choice of another possible determinant of Field Dependence-Independence: Locus of Control (e.g., Crandall and Lacey, 1972; Feather, 1967; Vernon, 1972). These studies revealed a link between an internal orientation in locus of control with field independence. Logically, the connection can be made between the two through the active cognitive processing which supposedly characterizes the internal individual and the field independent individual. (This connection is more thoroughly discussed in Chapter Two and in this chapter within the Locus of Control section.)

Finally, an argument was developed for the influence of Rigidity/Flexibility on Scientific Reasoning, supported by studies which examined the relationship between personality characteristics of individuals, including rigidity, and field dependence-independence (Breskin and Gorman, 1969; Gardner et al., 1959; Witkin et al., 1977). These studies indicated that the flexible individual had stronger spatial abilities than did the rigid individuals.

The hypotheses which were developed involving Field Dependence-Independence, then, were based upon research that (1) supports field independence as an aptitude for scientific reasoning; and (2) suggests Experience, Gender, Locus of Control, and Rigidity/Flexibility as determinants of Scientific Reasoning through the Field Dependence-Independence variable.

## Discussion of Hypotheses

Significant correlations were hypothesized as sub-hypotheses within Hypothesis I for Field Dependence-

Independence with the following variables: Scientific Reasoning, Experience, Locus of Control, Gender, and Rigidity/Flexibility. In Hypothesis II, Field Dependence-Independence was hypothesized to share significantly more variance with Scientific Reasoning in the older adolescent sample than in the younger sample, the reasoning being that the adolescent years would provide for the development of a stronger "aptitude" for Scientific Reasoning. A causal relationship within the model posited in Hypothesis III indicated a direct effect on Scientific Reasoning by the Field Dependence-Independence variable.

## Discussion of Results

Reference to the correlation matrix generated in testing the sub-hypotheses of Hypothesis I (Table 4-1) indicates that significant ($p <= 0.004$) correlations were obtained for Field Dependence-Independence and Scientific Reasoning. These findings concur with research by Weisz, O'Neill and O'Neill (1975), Niemark (1979), Adi and Pulos (1980), and Linn, Pulos and Gans (1981). Another significant correlation was obtained for Field Dependence-Independence and Locus of Control, as was expected on the basis of previous research findings of Feather (1967) and Crandall and Lacey (1972). Both of these sub-hypotheses were supported. A negative correlation obtained for Field Dependence-Independence and Rigidity/Flexibility resulted in the rejection of the hypothesis concerning these two variables. There were no significant correlations obtained for Field Dependence and Experience or for Field Dependence and Gender, relationships originally hypothesized to be significant. Problems with the design of the instrument measuring Experience may have resulted in the lack of significance with this variable. The possibility also exists that the basic conjecture that Field Dependence-Independence and Experience are linked is not likely to be supported empirically. A genetic basis for the development of field independence in adolescent males may be more accurate. The lack of significance in the relationship between Gender and Field Dependence-Independence is more surprising, due to substantial previous reports of relationship between these two variables.

With respect to relationships which were found to be significant which were not originally hypothesized, two were obtained. The first was between Field Dependence-Independence and IQ. Witkin et al. (1977) state that there is no basis for linking intelligence and field dependence-independence. The instrument used for measuring IQ in this research, however, was described as having been designed to strongly measure analytic thinking. The observed link may thus be explained. The second observed relationship was between Field Dependence-Independence and Age, a relationship not strongly supported in terms of previous research. As the test measuring the construct of Field Dependence-Independence was timed and required intense concentration, perhaps the ability of older adolescents to withstand these effects of testing may have manifested itself in higher scores on this test.

The finding from the testing of Hypothesis II, that the shared variance between Field Dependence-Independence and Scientific Reasoning is not significantly greater in the older adolescent population, indicates that the "aptitude" variable is not one which becomes stronger within the span of ages examined in the present study. Piaget's paper (1972) exploring reasons for the lack of formal thought acquisition in older adolescents was preliminary and speculative. From the findings of this research, these speculations are not supported.

When the hypothesized model for Scientific Reasoning was tested by path analysis, a direct effect of Field Dependence-Independence on Scientific Reasoning was supported, with an obtained path coefficient of 0.45 ($p < 0.02$) after the effects of all other variables impinging upon Scientific Reasoning were removed (Table 4-10.) In this multiple regression, Field Dependence-Independence contributed only 2% to the overall explained variance of 62% by the hypothesized model. In the revised model (Figure 4-3), the beta for Field Dependence-Independence in the equation was recalculated as a value of 0.15. The contribution of Field Dependence-Independence to the variance explained by the model was low: 1% out of the total of 61%.

## Conclusions

Field Dependence-Independence, chosen to represent the "aptitude variable" influencing the cognitive development of adolescents, was found to have a minor, though significant causal effect on Scientific Reasoning. This conclusion conforms to findings of Neimark (1979), Adi and Pulos (1980), Linn, Pulos and Gans (1981), and Nagy and Griffiths (1982) that a relationship exists between field independence and formal thinking. The finding from this study of such a small contribution of Field Dependence-Independence to Scientific Reasoning makes the conclusion rather weak, however.

Although not unchangeable, a characteristic of Field Dependence-Independence (and of other cognitive styles as well) is that it is stable over time.

> This does not imply that they [i.e., cognitive styles] are unchangeable; indeed, some may easily be altered. In the normal course of events, however, we can predict with some accuracy that a person who has a particular style one day will have the same style the next day, month, and perhaps even years later. (Witkin et al., 1977, p. 15)

Another conclusion of this research which relates to Field Dependence-Independence is that Locus of Control directly affects Field Dependence-Independence. This conclusion and its implications have been discussed previously in *B. Locus of Control* of this chapter. The implications which follow are based only upon the direct relationship of Field Dependence-Independence to Scientific Reasoning.

### Implications

An educational implication in terms of learning outcomes is that field-independent students should have less trouble in learning situations which require students to employ their reasoning abilities. Suggestions of ways to adapt the classroom environment to the reasoning differences which exist in these students have been reviewed previously. (See *A. Experience* and *C. Age*). Karplus suggested matching educational subject matter and assignments to students' reasoning abilities and adopting and/or developing curricula which are open-ended with conceptual teacher input. (See *Implications*, *C. Age* in this chapter.)

If the learning outcome is one of concept attainment, Witkin's review of research indicates that both field-dependent and -independent learners are equally capable of learning concepts, as explained below:

> The case seems well documented that relatively field-dependent and field-independent persons tend to favor different learning approaches. The approaches favored by one kind of person do not necessarily make for better achievement than the approaches favored by the other kind. Whether one approach will lead to a better learning outcome than others seems to depend rather on the specific characteristics of the learning tasks and

> the particular circumstances under which learning takes place. .... Beyond encouraging teachers to adapt their teaching to students as they find them, we may hope even more that teachers may find ways of helping students diversify their learning strategies. (Witkin et al., 1977, p. 27)

Witkin et al. suggest ways in which to identify field-dependent and field-independent students on the basis of predictable learning behaviors which include differences in the way students learn social material; in the effects of social reinforcement; in the use of mediating mechnisms in learning, and in cue salience. Differential treatment is recommended on the basis of these predictable differences in order to address the individual learning differences of these students. Student behaviors which may cue the teacher as to the orientation of a student along the field dependent-independent continuum are as follows: the field-dependent student learns social material more easily than does the field-independent student; that field-dependents learn more effectively with social reinforcement, while field-independent students need little external reinforcement; that the use of mediators is more characteristic of field independents than field dependents; and that the effects of cue salience are more pronounced for field-dependent than field-independent concept learners.

With a knowledge of these predictable behaviors and close observations of students, field-dependent and independent students may be identified. If the development of reasoning is an educational objective, strategies may then be implemented regarding effective long-range interventions designed to change the orientation of the student towards field independence. One way in which to change the field orientation is through the Locus of Control variable, as shown in the final path model for Scientific Reasoning which was developed in this research. Use of this knowledge in effecting change has been discussed previously in the section of this chapter which deals specifically with the results of the research concerning the Locus of Control variable. (See Implications in B. Locus of Control.)

## Recommendations

The statements by Witkin et al. (1977) regarding the differential learning styles of field dependents and field independents suggest that perhaps there may be interventions which, by addressing the learning preference of the field-dependent person, may enhance the development of scientific reasoning abilities. An exploration of aptitude-treatment effects is recommended in this regard. It is also recommended that differences in strategies used by field-dependent and field-independent students in learning science concepts be explored. The identification of other means, besides through Locus of Control, for modifying the field orientation of an individual is also recommended for further research. In this regard, redefinition and reexamination of an experiential variable may be warranted.

## E. Rigidity/Flexibility

### Overview of the Variable

A need to identify the elusive, "somewhat incomprehensible" equilibration component of Piaget's theory of cognitive development led this investigator to an examination of constructs which appeared in description to be similar to Piaget's descriptions of equilibration. Equilibration was explained by Piaget to be an "ineluctable rhythm," the mechanism by which an individual experiences the environment, acts upon that experience, and takes the experience into himself. Experiences discrepant to previous experience were theorized to set up a state of "cognitive disequilibrium," which is resolved when the individual modifies or replaces pre-existing mental structures so that the new experience is accommodated. Block (1982) attempted to redefine Piaget's cognitive disequilibrium from a psychological model, suggesting that mediating variables in the form of personality or cognitive style may affect the manner in which an individual approaches cognitive disequilibrium. Block speculated that some persons, in reacting to new experiences, encompass the new information in ways that require little or no modification of previously established premises. Other persons encountering discrepant experiences, having a greater readiness for leaving schemas that do not mesh readily with new experience, move on to the formulation of new and sufficient meaning-making structures.

Block suggested that individual differences exist in the manner in which individuals react cognitively to discrepant experience, and that these differences ultimately result in enhancing, retarding, or blocking the development of logical mental structures. It was from Block's suggestion and the theoretical framework of Frenkel-Brunswik (1949) that the personality construct of Rigidity/Flexibility was chosen as a probable construct affecting the resolution of cognitive disequilibrium and thus affecting the outcomes in scientific reasoning ability.

Frenkel-Brunswik's (1949) underlying rationale in constructing her thesis regarding an individual's rigidity or "intolerance of ambiguity" was based upon her acceptance of the close correspondence between belief, personality, and cognition in the perceptions which an individual has of his or her environment. Rigid individuals were theorized to exhibit a pervasive tendency toward premature closure and a general intolerance of cognitive ambiguity. As these tendencies would lead to inadequate cognitive resolution of situations producing cognitive disequilibrium, it was reasoned in the present research that rigid individuals, not being able to tolerate the ambiguity in these situations, would not develop patterns of scientific reasoning.

Breskin's Rigidity Test was developed by Breskin (1968) to substantiate Frenkel-Brunswik's theories regarding the rigid personality. This non-verbal test was chosen to measure the degree of rigidity or flexibility exhibited by adolescents in the two samples of this study.

## Discussion of Hypotheses

In Hypothesis I, high scores on Breskin's Rigidity Test, indicating high flexibility, were posited to correlate positively with higher Age, Field Independence, and higher abilities in Scientific Reasoning. The causal model of Hypothesis III included causal relationships with Age impinging upon Rigidity/Flexibility; and with Rigidity/Flexibility acting as a determinant of Field Dependence-Independence and of Scientific Reasoning. Higher scores in Flexibility were expected to determine Field Independence and high ability in Scientific Reasoning.

## Discussion of Results

Results of testing the correlational subhypotheses of Hypothesis I indicated that the high scores on Breskin's Rigidity Test, indicating high flexibility, were negatively correlated with all hypothesized variables. In other words, rigid individuals were field independent, higher in scientific reasoning, and older. And flexible individuals were field dependent, lower in scientific reasoning, and younger. All hypotheses were rejected on the basis of the obtained negative (rather than positive) correlations.

Similar findings were evident in the testing of the causal model of Hypothesis III: resulting path coefficients between the variables of Age, Field Dependence-Independence, and Scientific Reasoning and Rigidity/Flexibility were negative. The causal paths which were tested involved the following: Rigidity/Flexibility impinging upon Field Dependence-Independence; Rigidity/ Flexibility impinging upon Scientific Reasoning; and Age impinging upon Rigidity/Flexibility. Of these paths, only the path from Age to Rigidity/Flexibility was statistically significant (Table 4-8). The simple regression of Age on Rigidity/Flexibility resulted in an obtained beta of -0.32 ($p < 0.01$) and indicated that 10% of the variance in Rigidity/Flexibility could be explained by the Age variable. As the results of testing the other paths in the proposed model indicated that Rigidity/Flexibility impinged neither directly nor indirectly on any other variables within the model, the path from Age to Rigidity/Flexibility was removed; and Rigidity/Flexibility was excluded from the final model for Scientific Reasoning.

## Conclusions

The findings of the present research indicate that Rigidity/Flexibility, as measured by Breskin's Rigidity Test, has no theoretically significant causal relationship within the model for Scientific Reasoning.

## Implications

As the results of this study indicate no significance of the Rigidity/Flexibility variable in the final, "trimmed" model of Scientific Reasoning, implications are restricted to theoretical implications relating to the obtained negative correlations which were not originally predicted. The hypotheses regarding Rigidity/Flexibility were based on the interpretation that, as full-functioning, self-actualizing individuals grow in age and experience more in their environment, they become more flexible in dealing with situations unlike those previously experienced. Field independent, older, and high-ability scientific reasoners would therefore, it was reasoned, be more likely to score higher in Flexibility on the Breskin's Rigidity Test. Correlational data indicated results opposite to those which were originally expected. Similarly, results of testing the causal model indicated a causal relationship with Age acting as a determinant of higher scores in rigidity, not flexibility. These findings indicated that a reexamination of the original reasoning might be warranted.

A reinterpretation of the theory forming the framework for this research resulted in reasoning that, with age, the relatively free, flexible young child develops more structured, disciplined thought patterns. These thought patterns, though rigid, enable an individual to interact more freely with the environment on the basis that reasoning is also associated with full-functioning individuals who have control over emotional responses to unexpected circumstances in the environment. On the basis of this reinterpretation, the original hypotheses concerning Rigidity/Flexibility, would have been constructed so that that high scores in Rigidity, not Flexibility, would correlate with higher scores in Age, Scientific Reasoning, and Field Independence.

There are theoretical implications also regarding gender differences which may exist in the relationship of Field Dependence-Independence and Rigidity/Flexibility. Previous research (e.g., Breskin and Gorman, 1969; Gardner et al., 1959) indicated gender differences in the relationship between the two variables, with only women showing a relationship between field dependence and rigidity. These results do not concur with the findings of the present research, which indicated that rigidity was correlated with field independence for all individuals.

Implications regarding the educational significance of Rigidity/Flexibility in a model for Scientific Reasoning can not be made on the basis of the findings regarding this variable. On the basis of the findings of this research, other constructs or instruments which may be used to simulate an equilibration component are implicated.

Recommendations

An investigation for personological variables other than Rigidity/Flexibility which may operationally define or aid in the identification of Piaget's elusive equilibration component is recommended. Suggested is an exploration of the impulsivity-reflectivity dimension of cognitive style (Messer, 1976). This dimension, often called "cognitive tempo," has been implicated in previous research reviewed by Messer as a prerequisite of analytic thinking; an overlap of reflectivity and field independence has also been observed in some cases.

For individuals interested in the Rigidity/Flexibility construct, gender differences regarding the relationship of Rigidity/Flexibility and Field Dependence-Independence are suggested. Previous research by Gardner et al. (1959) and Breskin and Gorman (1969) indicate differences in the relationship of rigidity to field dependence-independence on the basis of gender, with only females showing a relationship between rigidity and field dependence. Strong a priori reasoning on the basis of these and other studies may be promising in terms of shedding light on the confounded results presented here regarding the relationships of Gender, Field Dependence-Independence, and Rigidity/Flexibility.

## F. IQ

### Overview of the Variable

A definition of IQ was adopted in the present research which assumed the IQ score to be a measure of general functioning intelligence, conditioned by native potential but not completely limited by it. Other factors of motivation and environmental stimulus were also recognized as playing a role in the general functioning intelligence exhibited by the IQ test (Taba, 1962). Educational significance of the IQ score was recognized on the basis of its general identification as a measure of "ability to learn" (as discussed by Cronbach and Snow, 1977).

IQ was chosen for exploration in the model for Scientific Reasoning on the basis of previous research findings, sometimes contradictory, regarding the relationship of IQ to cognitive development (e.g., Cloutier and Goldschmid, 1976; DeVries, 1974; Keating, 1975; Weisz, O'Neill and O'Neill, 1975). For instance, IQ was shown to predict precocity in cognitive development of young adolescents (fifth and seventh graders) by Keating (1975); it was also compared to performance on Piagetian tasks and was shown to measure different dimensions of intelligence (Cloutier and Goldschmid, 1976; DeVries, 1974); and it was evaluated as a "cheaper and more reliable proxy measure" of cognitive developmental level than Piagetian tasks designed to measure cognitive level (Nagy and Griffiths, 1982).

The measure of IQ in the present study was a composite total IQ score from the Short From Test of Academic Aptitude, a group test which is administered every other years to school children in the school district from which the samples of adolescents were drawn. The test booklet for this instrument described the IQ score as a reliable estimate of the relative brightness of the student, emphasizing intellectual functions of a relatively abstract nature, with total score on the test being "the most dependable estimate of general ability" (Short Form Test of Academic Aptitude, 1970, p. 6).

## Discussion of Hypotheses

A significant positive correlation was posited for IQ and Scientific Reasoning, with higher IQ scores indicating higher scores in Scientific Reasoning (Hypothesis I). In Hypothesis II, it was hypothesized that IQ would share a significantly greater amount of variance with Scientific Reasoning in the younger sample than in the older sample of adolescents. In the development of this hypothesis, it was reasoned that IQ would show this relationship if it indeed indicated precocity in the reasoning abilities of young adolescents, as shown previously by Keating (1975). The causal model of Hypothesis III included a path from IQ directly influencing Scientific Reasoning.

## Discussion of Results

The finding that IQ was significantly correlated ($r$ = 0.48, $p <= 0.004$) with Scientific Reasoning (Hypothesis I) indicated a moderate amount (23%) of shared variance between the two variables. This finding concurred with previous research reviewed by DeVries (1974) which indicated low to moderate correlations between the two variables. From the testing of Hypothesis II, IQ was not supported as an significant indicator of high amounts of scientific reasoning in young adolescents; shared variance between IQ and Scientific Reasoning were not significantly different in older and younger groups. Regarding Hypothesis III, testing the revised path from IQ to Scientific Reasoning (Table 4-20), resulted in an obtained path coefficient of 0.49 indicating a strong causal effect of IQ on Scientific Reasoning. After the effects of the other variables impinging upon Scientific Reasoning (Field Dependence-Independence, Experience, and Age) were removed, the addition of IQ to the regression equation resulted in a change of explained variance from 40% to 61%. The addition of IQ therefore contributed 21% of the variance explained by the revised model for Scientific Reasoning.

## Conclusions

IQ is identified as a strong determinant of Scientific Reasoning on the basis that IQ remained a strong determinant, accounting for an additional 21% of the explained variance in the model for Scientific Reasoning, after the effects of other variables in the model were removed. The IQ score, as measured by the Short Form Test of Academic Aptitude and defined in the present research as a measure of general functioning intelligence, or "ability to learn," has educational significance in terms of its relationship to Scientific Reasoning.

## Implications

There are educational implications regarding "ability to learn," as indicated by the IQ score, in terms of generating expectations of for children in learning to reason scientificially. Higher IQ scores generally predict higher abilities in Scientific Reasoning; they also indicate that learning should come easier for these children (Cronbach and Snow, 1977). Children with higher IQs, therefore, should be expected to have less difficulty with materials requiring the use of reasoning skills; and in situations where the teacher expects children to improve in their reasoning, children with higher IQs should improve more easily, and probably faster, than those with lower IQs. On the other hand, children with lower IQs should be expected to have more difficulty with materials requiring the use of reasoning skills; and in situations where reasoning is expected to improve, these children should improve more slowly and with more difficulty.

If a commitment has been made to the teaching of reasoning as well as to the teaching of content, suggestions by Karplus (1979), discussed in C. Age of this chapter, are definitely applicable. The expectations regarding differences in IQ as described above should be taken into account in selecting concepts, determining instructional sequence (i.e., implementing the learning cycle), and exhibiting particular teacher behaviors. Knowing that children with lower IQs may have difficulty in reasoning tasks and abstract concept mastery, strategies addressing these needs are implied for lower-ability children classified as such by lower IQ scores.

## Recommendations

A moderate correlation ($r$ = 0.30) between IQ and Field Dependence-Independence suggests an exploration of this relationship, particularly as Witkin et al. (1977) have issued strong statements to the contrary regarding the relationship of intelligence to the construct of field dependence-independence.

## G. Gender

### Overview of the Variable

Conclusive evidence has been cited in recent reviews (Archer and Lloyd, 1982; Maccoby and Jacklin, 1974; Petersen and Wittig, 1979) which supports the existence of gender differences in some areas of cognitive functioning, but which also acknowledges that differences between sexes are not as widespread as was once commonly supposed. Of particular interest in the present research is evidence cited which indicates the emergence at adolescence of differences in spatial ability and mathematics, with boys becoming more proficient than girls. The choice of field independence (often used synonymously with the term "spatial ability") as the aptitude variable for Scientific Reasoning led to the exploration of theories regarding the observed differences in spatial ability of adolescent boys and girls. The sources which have been implicated as causing the observed differenes include differential experiences (both out-of-school and in-school) (e.g., Fennema and Sherman, 1977; Kahle, 1983; Sherman, 1967); social effects, as measured by locus of control (Crandall and Sinkeldam, 1964; Yalom, 1980) and genetic/endocrinological effects (Treagust, 1980). Petersen and Wittig believe that differences in cognitive functioning arise as a result of the interactive influences of brain organization, endocrine influences, socialization, and educational experiences.

## Discussion of Hypotheses

Correlational hypotheses (Hypothesis I) were developed for significant relationships of Gender and these variables: Locus of Control, Experience, and Field Dependence-Independence. In Hypothesis III, only indirect effects of Gender on Scientific Reasoning, through the variables of Locus of Control, Experience, and Field Dependence-Independence, were hypothesized.

## Discussion of Results

The results of testing the sub-hypotheses of Hypothesis I involving the Gender variable revealed no significant correlations between Gender and any other variable. Similar results in testing Hypothesis III were obtained when the paths involving Gender in the hypothesized model for Scientific Reasoning were tested by regression techniques. The calculation of the path coefficient from Gender to Locus of Control (Table 4-14) resulted in a beta of 0.09, accounting for 1% of the variance in Locus of Control by the Gender variable. The path from Gender to Experience (Table 4-15), with a beta of -0.01, indicated that variance in the Experience variable attributed to Gender was less than 1%. Finally, the effects of Gender on Field Dependence-Independence (Table 4-16) after removal of the effects of Rigidity/Flexibility, Experience, and Locus of Control were removed, resulted in a beta of 0.02 and no increase in the amount of variance in Field Dependence-Independence explained by the addition of the Gender variable. On the basis of these findings, all paths involving Gender were removed in the revision of the hypothesized model.

An explanation for these results perhaps may be found in an examination of the population from which the boys and girls were chosen for this study. The community from which the samples were drawn for the present study was an upper middle class suburb, which may have been more homogeneous in terms of impinging background variables previously defined as differentially affecting the cognitive development in boys and girls. Characteristics of the members of this community such as high education levels of both parents, a high incidence of mothers working outside the home, exposure to appropriate professional female role models for girls, equal exposure to activities identified as influencing the development of field independence (and scientific reasoning), and expectations regarding college education and career choices for girls may have led to the unexpected finding of no gender effects observed in this study. These effects as well as the increasing independence of females in being able to support themselves, decide on careers other than homemaking, and choose courses of study which include mathematics and/or science in order to prepare them for college and/or professional careers may have caused the nonsignificant effects of Gender on Locus of Control. Girls and boys both may be approaching equal distributions in the numbers representing internals and externals as a result of the decline in differences between their functioning at adolescence and before. The school system from which the sample was drawn may also have affected the finding of nonsignificant effects of Gender. Elementary and middle schools in the school system embrace a philosophy of exposure to science which is primarily laboratory based and inquiry orinted throughout the first nine grades of school. Differential exposure of boys and girls to science content is not possible until the ninth grade, at which time the children make choices regarding science courses they will take at the high school level. The sample of older adolescents, drawn from classes in General Chemistry, English Literature and Composition, and General Humanities, and spanning grades 9, 10, and 11, probably have had at least one additional science course past their elementary and middle school exposure. Equal exposure to nine years of school science curricula may therefore have been responsible for the lack of evidence for causal effects of Gender upon Experience.

Also in regard to Gender and Experience, no gender differences were evident with the hypothesized experiential variable; involvement in activities identified as influencing the development of spatial abilities and/or scientific reasoning and appearing in the Cognitive and

Recreational Activity Scale appeared to be similar between boys and girls. There was therefore no indirect effect of Gender on Field Dependence-Independence through the Experience variable.

Nor was there evidence for a direct effect of Gender on Field Dependence-Independence, such as might occur if the origin of field independence in adolescent males was indeed genetic-endocrinological as suggested by Treagust (1980).

## Conclusions

Although there was evidence from previous studies to support the existence of gender differences in cognitive functioning of adolescents, there is no support from this study to indicate that Gender indirectly affects Scientific Reasoning through any of the variables explored in the present study.

## Implications

These findings indicate that gender differences may exist in only some populations of adolescents. Gender differences may not be evident in populations from communities which are socioeconomically upper middle-class; which are composed of high numbers of professionals, with high levels of education for both mothers and fathers; and which are served by a school system which values inquiry-oriented and laboratory-based science curricula. In the particular population samples for this study, there are no implications for significant differential exposure or treatment to girls in the educational setting. There were no significant relationships between Gender and the other variables explored on which to base implications of the findings of this research.

## Recommendations

Comparative studies of populations differing in socioeconomic backgrounds and/ or consistent early exposure to science are recommended with the purpose of identifying variables which differentiate populations exhibiting gender differences in Scientific Reasoning, Locus of Control, and/or Field Dependence-Independence, from those which do not.

## Section II. Discussion, Conclusions, Implications, and Recommendations Regarding Significant Findings of the Research

### Discussion of the Significant Findings of the Research

The comparison made in the Summary Statement of Chapter Four of the results of testing Hypothesis I by correlational methods and Hypothesis III by path analysis attests to the value of causal modeling in determining the nature of the hypothesized relationships between variables in the study. Values of correlative data in nonexperimental research are in obtaining correlation coefficients which indicate magnitude, direction, and shared variance between correlated pairs of variables. Pedhazur states that correlational data may be suggestive of causal linkages, but

> An explanatory scheme is not arrived at on the basis of the data, but rather on the basis of knowledge, theoretical formulations and assumptions, and logical analysis. *It is the explanatory scheme of the researcher that determines the type of analysis to be applied to data, and not the other way around* [italics added for emphasis]. (Pedhazur, 1982, p. 579)

The correlations obtained in the present study indicated the strength of several variables in predicting Scientific Reasoning, but these data could not be used to imply causality. The fact of reversibility made it impossible to formulate notions of causality on the basis of correlational data alone. The purpose of the research was not only to predict Scientific Reasoning, but to reveal causal relationships underlying observed differences in scientific reasoning abilities. Although this study was not experimental in nature, the model testing procedures of path analysis enabled the exploration of a number of variables proposed to be in causal relationship with one another, as well as with Scientific Reasoning. Results of path analysis were expected to simplify the model and to restrict it to causal paths supported by the data.

The causal model which was originally designed for Scientific Reasoning was based upon a strong theoretical framework, assumptions based upon philosophies of human functioning, cognitive development, the nature of science, and educational psychology; and empirical evidence from prior research related to the variables which were identified as potential determinants of Scientific Reasoning. The model for Scientific Reasoning which resulted was exploratory, but the causal relationships proposed were strongly supported. Causal relationships as paths within the model were tested by path analysis. The regressions performed in this testing procedure resulted in path coefficients which were either significant or nonsignificant at the $p <= 0.05$ level of significance. Those paths supported by the data were included in a "trimmed" model for Scientific Reasoning, shown in Figure 5-1. Path analysis used in this manner allowed a model which

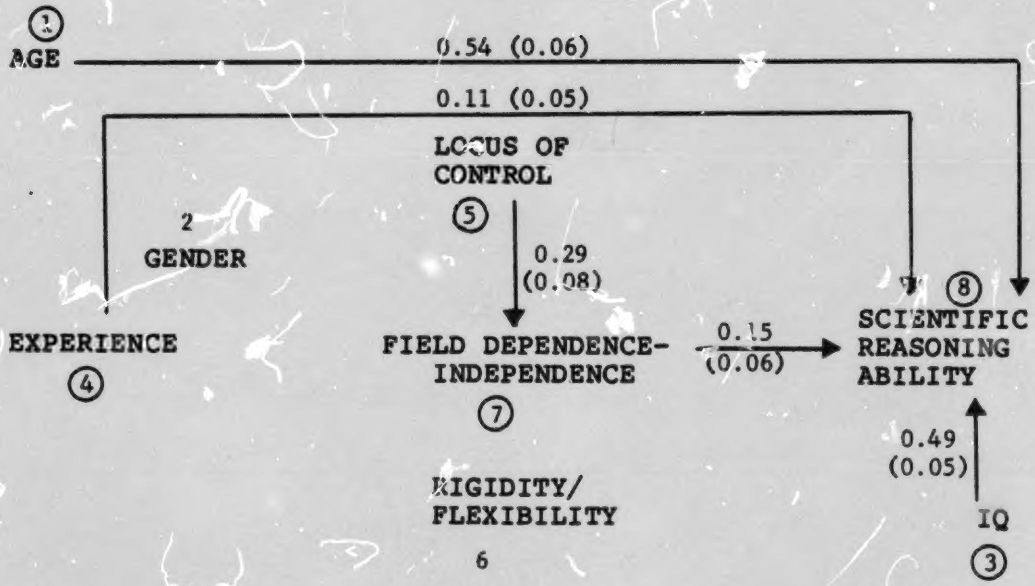

①
AGE
0.54 (0.06)
0.11 (0.05)
LOCUS OF CONTROL
⑤
0.29 (0.08)
2
GENDER
EXPERIENCE
④
FIELD DEPENDENCE-INDEPENDENCE
⑦
0.15 (0.06)
⑧
SCIENTIFIC REASONING ABILITY
0.49 (0.05)
IQ
③
RIGIDITY/ FLEXIBILITY
6

Fig. 5-1. The final revised causal model displaying significant ($p < 0.05$) relationships between variables shown to have direct and/or indirect effects on Scientific Reasoning. The path coefficients appearing in this model are the standardized beta weights obtained in regressions performed during the testing of this model.

was introduced in an exploratory sense to be simplified to paths for which this data showed support. The results of the testing of the paths were not interpreted to mean that paths which were not significant were "wrong"; rather, these paths were not supported by the data collected with this sample of adolescents, drawn from a particular educational setting within a particular community.

The data from correlation and regression analyses has led to an understanding of the final path model which is presented in Figure 5-1. Path coefficients were calculated as the standardized beta weights, from which comparisons can be made as to magnitude of the causal effect of one variable impinging upon another. A comparison of standardized beta weights indicates that causal effects of Age and IQ on Scientific Reasoning are high (0.54 and 0.49, respectively); that causal effects on Scientific Reasoning of Field Dependence-Independence and Experience are low (0.15 and 0.11, respectively); and that the causal effect of Locus of Control on Field Dependence-Independence is moderate (0.29).

Also of importance in this model is an understanding of the actual variance in the dependent variable which is attributed to its determinant. On this basis, Age and IQ definitely account for much larger portions of variance in Scientific Reasoning than Field Dependence-Independence and Experience. The amount of variance in Field Dependence-Independence accounted for by Locus of Control is also small. The overall explanation of variance in Scientific Reasoning by the simplified model composed of these determinants is 61%.

The revised model indicates strong direct effects of Age and IQ on Scientific Reasoning, and weak direct effects of Experience and Field Dependence-Independence on Scientific Reasoning. As well, evidence was provided from this study for the indirect effect of Locus of Control on Scientific Reasoning through the Field Dependence-Independence variable.

## Implications Regarding Significant Findings of the Study

Implications of the findings regarding the individual variables of this study are discussed in detail in Section I of this chapter. More general educational implications for the findings of this research relate to the evidence for causal effects on Scientific Reasoning of Experience and Locus of Control, which have implications for variables which may be manipulated directly; and for the causal effects of Field Dependence-Independence, Age, and IQ on Scientific Reasoning. which have implications in terms of individualizing instruction to meet the needs of children exhibiting differences in the usual heterogeneously grouped classroom. The discussions which follow incorporate implications regarding individual variables into three major categories: implications for the role of the science teacher, implications for classroom management, and implications in terms of science curriculum. These sources have been used extensively in the discussions which follow: Karplus (1979), Rowe (1977), Shayer and Adey (1981), and Witkin et al. (1977).

## Implications for the Role of the Science Teacher

The findings of this research implicate roles for the science teacher as planner, facilitator, and evaluator. As a planner, the teacher must be aware of levels of content which his/her students are required to master, as well as the individual characteristics of students which may or may not match with that content. The results of this research indicate that the teacher's expectations regarding reasoning abilities of students can be based upon their general age level their IQ scores, and upon observed behaviors which indicate their field orientation. The teacher can generally expect children who are older, who have higher IQs, and who exhibit behaviors related to field independence to exhibit higher level reasoning patterns. Regarding age, a teacher can expect heterogeneity in terms of reasoning patterns, but generally that older children will be better reasoners than younger children. Differing IQs and field orientiation may affect expectations in scientific reasoning based upon age. Differences in IQ will lead to differences in expectation regarding rate at which students will learn concepts as well as adopt new reasoning patterns. Regarding concept mastery, those concepts which require more "abstract" reasoning patterns will be more difficult for lower level reasoners, children lower in IQ, and field dependent children. Differences in field orientation will lead to observed differences concerning the ways in which children learn concepts, which they may also apply in their learning to reasoning. Although no difference in the ultimate effects due to field orientation should be expected in the learning of concepts, differences can be expected in the effects due to several sources, such as the nature of the material to be learned (i.e., social material), effects of social reinforcement, effects due to the use of mediating mechanisms in learning, and effects due to cue salience.

As a facilitator, the teacher must be aware of what the outcomes are for the learning which is to take place in the science classroom. If the expected learning outcome is an increase in reasoning, teachers should develop an attitude which encourages the intrinsic rewards of learning rather than extrinsic, knowing that teacher praise as a reward may not encourage independence in learning and understanding that the development of an intrinsic reward system leads to the development of scientific reasoning. Teachers' input should be conceptual, with questioning that makes students aware of the intellectual processes involved in their answering of questions. Teachers' questions should stimulate reasoning by requiring students to support their answers on the basis of available evidence. Teachers should also encourage students to be reflective in their answers: to take their time to think, to examine a number of alternative answers which may be plausible, and to demonstrate uncertainty about inferences when it exists.

The teacher as evaluator must evaluate concepts in terms of the level of reasoning required for their understanding. Concepts are evaluated in terms of the extent to which the teacher believes that the student could understand a concept through (1) direct experience and the use of concrete reasoning patterns or (2) inferences from experience and the use of formal reasoning patterns. Regarding the evaluation of specific concepts, a curriculum analysis taxonomy can be an important tool in determining the level of reasoning required by students for their mastery.

Also as evaluator, the teacher must evaluate the students' level of reasoning. General expectancies can be generated regarding age level, ability in terms of IQ, and field orientation. As well, information regarding level of reasoning can be gained from close observations of individual students during class discussions, on homework assignments, and in conversations in which the student explains his ideas, justifies inferences, presents evidence, or defends his or another's point of view. In secondary and college science courses where contact with individual students is limited, a test to determine functioning level of reasoning may be helpful in the evaluation of the student's level of reasoning.

These roles are not separate, as discussed above. Instead, an integrated approach to teaching is required in order to teach reasoning. The teacher must plan for individual differences which have been shown to make a difference in the reasoning patterns of students; individualized instruction which matches level of understanding required of content with level of understanding of student is offered as the ideal situation. In the usual case of heterogeneously grouped, large-sized classes, a focus on reasoning will necessarily depend upon the teacher's commitment to the teaching of reasoning and an expenditure in energy which does not reveal itself in conventional terms regarding the learning of science content.

## Implications for Science Classroom Management

Suggestions for classroom management are based primarily upon implications by Karplus and Rowe that reasoning develops in students when individual student involvement is high, when learning is student-centered and student-directed, with student motivation which is intrinsic, with teacher involvement which is facilitative, and where there are ample opportunities for social interaction, hands-on science activities involving the concrete manipulation of objects, and logico-mathematical thinking. Open-ended, inquiry-oriented science laboratories are implicated as providing many of the opportunities listed above. Small group interaction in the science laboratory is suggested, where students talk about what they have done and observed, argue about what they make of their observations, refine and finally design new experiments to test new ideas, and ask new questions as a direct result of their inquiry. Group process facilitation was also suggested by Rowe as appropriate. Opportunities in self-regulation are therefore provided for students to be involved in the "feedback loop with their environment," as discussed by Karplus. Involvement with the teacher is implicated as primarily conceptual, with the teacher stimulating reasoning by the types of questions which are asked and by encouraging a student to be aware of the intellectual processes involved in the answering of questions. Implications for the reasoning-oriented classroom in terms of teacher involvement are that the teacher will be cognitively very involved with the questions and answers he/she receives as a direct result of experiences occurring within the classroom in which the student is an active participant.

Implications for Science Content

Science content in a curriculum designed for scientific reasoning should be offered within a framework which is open ended, inquiry oriented, and experientially based in activities requiring spatial visualization, concrete manipulation of objects, and logico-mathematical thinking. Concepts, evaluated as to the reasoning level required for adequate understanding, should be introduced according to an organization such as Karplus' learning cycle: concept exploration, concept introduction, and concept application. In this cycle, concepts are introduced after exploratory experiences in which students learn through their own actions and reactions in a new situation. The teacher at that time encourages the student to relate new experiences to existing knowledge. New experiences should then lead to questions which students cannot answer with their accustomed patterns of reasoning. Individual investigations and small group work are suggested to provide a supportive social environment and additional sources for new ideas and suggestions. Concept introduction relates directly to the exploratory experiences; and students are required to apply new reasoning patterns as a result of the concepts introduced. Cognitive disequilibrium may result, particularly if the application of new reasoning patterns in difficult. Teacher input at this time is supportive and encourages the student in the self-regulative process to take his time in analyzing how the previous experience relates to the particular concept in question. In concept application, the student applies the new concept or reasoning pattern to additional examples; more class time and opportunities for self-regulation are provided in order to stabilize the new concept or principle. Group discussions at this point lead to the expansion of applications and also aid students whose conceptual organization takes place more slowly than average.

Implications for science curriculum geared towards the development of reasoning rely heavily on implementing strategies for improving the match between level of reasoning required for the understanding of content and existing student's level of reasoning patterns. When differences do exist, alternatives include rejection of the concept as inappropriate; the breakdown of a concept into subobjectives which may lead to a description of many different levels at which the student may attribute meaning and therefore differing depths of understanding of the concept; and consideration of where in the pupil's school career it may be appropriate in terms of reasoning level to introduce the subobjectives of a particular concept. Shayer and Adey offer the following example:

> One example is reaction kinetics in chemistry and biology, where a traditional approach through rate equations constitutes a "high energy barrier" for most pupils. In this particular case a perfectly valid level of understanding can be reached at the late concrete level simply by arranging to keep the volume

> of the system constant while one reagent is doubled in quantity. The consequent doubling of the reaction rate will generalise easily at that level of a principle of speed increasing linearly with the amount of reagent. Such an understanding in a pupil with no system of chemical concepts may be of limited value in chemistry, but a significant aid to understanding some concepts in biology. (Shayer and Adey, 1981, p. 130)

With the emphasis on the teaching of scientific reasoning, extensive teacher training is implicated in terms of content mastery. Mastery of science content involves an underlying understanding of the relations between the nature of science and science knowledge; an underlying understanding of the conceptual framework out of which the particular science discipline arose; an underlying understanding of the relatedness of all disciplines of science in terms of processes by which science knowledge is acquired; and abilities to apply universal concepts (such as equilibrium, speed of reaction, chemical reaction, structure and function, and energy) to specific content areas of biology, chemistry, and physics. A knowledge of these generalized science concepts allows the teacher to aid students in generalizing beyond the particular to the more abstract, universals of science. As the student's abilities to abstract increase, so should his powers of reasoning (Karplus, 1979; Shayer and Adey, 1981).

Also implicated in terms of teacher training for the acquisition of skills in teaching reasoning are that teachers possess an understanding of general intellectual development in children; and an understanding of other individual differences which may impinge upon the abilities of children to reason; an understanding of appropriate strategies, behaviors and educational settings provided by the teacher which enhance the opportunities for children to grow intellectually. If the teaching of reasoning is an objective of a science curriculum, familiarity with the content of a specific science discipline alone is no more adequate for the teacher than it is for the student. Conceptual understanding implies mastery in its broadest sense.

## Recommendations for Further Study Based Upon the Significant Findings of the Study

The inclusion of paths within the final model for Scientific Reasoning was based exclusively upon the findings of the present research effort. The revised model accounts for 61% of the variance obtained for Scientific Reasoning. There are obvious areas, excluding error, which can be investigated in order identify additional sources for the variance unaccounted for by the revised model. The recommendations which follow are made on the basis of the model for scientific reasoning and on the basis of findings regarding the particular variables which have strong applications to research in science education.

When the model was originally hypothesized, the Rigidity/Flexibility construct was chosen to represent the equilibration component of Piaget's theory of cognitive development. The most appropriate measure found for that construct was Breskin's Rigidity Test, and the findings regarding the use of that test resulted in a reconsideration of some basic premises upon which the original hypotheses were made regarding Rigidity and Scientific Reasoning. Even with this reconsideration, Rigidity/Flexibility was found to be determined in large extent by Age and had no significant effects on other variables within the model. It is recommended on the basis of these findings regarding the particular Rigidity/Flexibility construct that perhaps another equilibration-like construct should be investigated in its relationship to other variables within the model. In this regard, the impulsivity-reflectivity dimension of cognitive style (Messer, 1976) is suggested as a possibility. Messer cites previous research which implicates impulsivity-reflectivity (often called "cognitive tempo") as a prerequisite of analytic responding. There is also research which indicates a moderate overlap of reflectivity and field independence in some cases. Block (1982) also suggested a relationship between impulsivity-reflectivity and the Piagetian concept of equilibration in the development of personality. Most instruments developed for testing this construct are individually administered and timed; the administration of these tests, therefore, becomes a great consideration in model building studies which necessarily require high numbers of subjects.

The unexpected results concerning gender differences also point to an area for further research. Suggested in this regard are comparative studies of adolescents from other school districts and/or communities. The homogeneous nature of this particular population has been discussed previously, and several reasons were posited regarding the lack of evidence for gender differences in this population. The extensive research in the area of gender differences in cognitive functioning, and in particular the implications by Sherman, Kahle, and Rowe that girls require remedial educational opportunities in order to develop spatial abilities, and experiences which stimulate internal self-dependency rather than external sources of reward, suggest to this investigator that gender differences should be important in determining relationships among variables which ultimately affect the development of scientific reasoning.

The results of this study lead to a number of questions regarding the effects of age on a number of variables originally included within the hypothesized model. Correlates of age which were observed and not expected were with the variables of Rigidity/Flexibility and with Field Dependence-Independence. Results used to determine the final model indicate strong effects of Age on Scientific

Reasoning itself. The question arises as to how many of the variables in the study are actually age-dependent. Although Witkin et al. do not suggest that the development of field independence is age-dependent, the correlation observed for this relationship does raise the question. Breskin, as well, indicated that scores on the instrument used to measure Rigidity/Flexibility were not age-dependent. The findings of this research indicate that further research may be necessary in this area. That no age effects were observed between groups in the relationship of a number of variables to Scientific Reasoning lead to questions regarding the lack of observed differences. Perhaps the groups were not well separated by the samples of young and old adolescents chosen; this possibility was discussed earlier in Section I. Evidence for age differences have numerous educational implications, and it is recommended that a search be made for particular variables which appear to be crucial for intellectual development at particular times in the ages of children, such as at the time of puberty when differences in spatial abilities are first observed for boys and girls. Theoretically, a model for the development of adolescent reasoning could be posited and tested on the basis of hypotheses similar to those posited in Hypothesis II of the present research. The educational significance of a pivotal determinant such as Experience in the development of Scientific Reasoning at early adolescence, for instance, could be considerable. Support which is now lacking would be available for particular experiences in science, such as the manipulation of objects which occurs in laboratory situations, or logico-mathematical requirements which come about in open-ended inquiry science (Blosser, 1981; Welch, 1980). Experience on the basis of the present findings, however, was shown to have no strong effects on the development of Scientific Reasoning during the time span of adolescence which was examined.

Experience was also a theoretically important variable in the conceptualization stage of this research. The indication of overall minor effects of Experience, regardless of age, on Scientific Reasoning suggest a reexamination of the variable as originally defined. Again, strong evidence is lacking to support the need for laboratory in the learning of science (Blosser, 1981). Evidence within this model for the existence of a link between experience and scientific reasoning would lend support to the implementation of science curricula which are experience based and inquiry oriented, originally developed upon the basis of theoretical (most often Piagetian) considerations alone.

Other recommendations relate to the Locus of Control variable, which appears to have implications in terms of a suggested relationship to Experience and an observed causal effect on Field Dependence-Independence. Locus of Control as "fate control" in Rowe's (1977) paper is implicated heavily in terms of science education. Rowe suggests that early science experiences lead to the development of internality regarding fate control. Evidence to support this speculation would indeed be valuable in the advancement of science education in elementary through college curricula. Research in this area has strong implications if support should be found to indicate that these change in perceived sources for reward do indeed occur. Intrinsic motivation is considered to be essential in the development of full-functioning adults and the perpetuation of a democratic society. Science experiences would take on new meaning if evidence could be found that science is an effective medium for the the development of internal reward systems.

Experimental research supporting the causal link observed in the present study between Locus of Control and Field Dependence-Independence also is recommended. Numerous studies have shown that relationships exist between field independence and science achievement, science concept mastery, analytic thinking, problem solving, and formal operational thought. If empirical studies indicate that Locus of Control can be manipulated in order to induce the development of field independence, implications could be drawn regarding ultimate outcomes in science learning.

## Summary Statement of Chapter Five

Conclusions which were drawn from this research are based upon the empirical evidence provided by the data acquired from the students in this study. These conclusions enabled comparisons to be made with previous research; and some results, particularly those dealing with gender differences which were anticipated to be present, were surprising. As well, the data supported a number of hypothesized paths, namely that Age and IQ were strong determinants of Scientific Reasoning; Experience and Field Dependence-Independence were weaker determinants of Scientific Reasoning; and that Locus of Control impinges upon Field Dependence-Independence, thus providing an indirect effect upon Scientific Reasoning by the Locus of Control variable.

The value in the empirical results of this study, however, is not restricted to the knowledge gained from the research effort. Particularly valued in educational research are the practical implications of the significant findings of the research. The results of this research effort led to implications regarding the implementation and/or modification of the educational variables found to directly or indirectly impinge upon Scientific Reasoning. Implications relating to the evidence for causal effects on Scientific Reasoning of Experience and Locus of Control involve the direct manipulation of these variables. The implications for the finding that Age and IQ have direct effects on Scientific Reasoning suggest individualizing instruction to meet the needs of children exhibiting differences of age and IQ which occur in the usual heterogeneously grouped classroom. As a result of these findings, implications were discussed in the latter section of this chapter regarding strategies for improving the development of Scientific Reasoning in adolescents, under the general topics of science teacher behavior, classroom management, and appropriate choices for science content.

The exploratory nature of this study led to a number of recommendations regarding further research aimed at exploring other factors which may impinge upon Scientific Reasoning. Of particular importance were recommendations that other variables be identified which may impinge upon Scientific Reasoning; that Rigidity/Flexibility be replaced with another equilibrium-like construct (perhaps something similar to Messer's impulsivity-reflectivity construct); that the effects of gender in the model be explored in more detail, particularly regarding the hypothesized but not supported indirect relationships posited in the original model; that the effects of age on other determinants of Scientific Reasoning be explored further, particularly in regard to the finding that no significant differences were obtained for the younger and older adolescent populations in the relationship of particular variables to Scientific Reasoning; that the variable of Experience, a theoretically important variable, be re-examined (and perhaps redefined) in its relationship to the development of Scientific Reasoning; and that experimental research regarding the manipulation of the Locus of Control variable be conducted to effect change in field orientation as well as change in Scientific Reasoning abilities.

The study which was conducted was descriptive in nature, seeking to gain information regarding hypothesized relationships between and among variables impinging upon Scientific Reasoning. Results of this research indicate that elements internal and external to adolescents affect their powers of Scientific Reasoning, and therefore their potential for becoming scientifically literate adults. In order to promote scientific literacy in the general public, therefore, this research indicates that we must not only acknowledge the importance of the external elements of the environment (such as the Experience variable in the present research) and the genetic characteristics of individuals (such as the IQ and Age variables) interacting within that environment. We must also acknowledge the internal elements of the individuals themselves (such as Locus of Control and Field Dependence-Independence) which have been shown to either enhance or discourage the overall development of rationality in adolescents.

# APPENDIX A

# RATING SHEET FOR ITEMS WITHIN THE COGNITIVE AND RECREATIONAL ACTIVITY SCALE

The following is a list of activities which are common for children of adolescent age. Please rank them as to how you feel participation in these activities would contribute to the development of scientific reasoning abilities (i.e., logical thinking processes) in children of adolescent age.

3 = high contributes
2 = moderately contributes
1 = might contribute a little
0 = does not contribute at all

1.2 earning money

1.4 doing sports

2.7 solving word problems in math

1.5 reading newspapers

1.5 watching TV science programs

2.1 doing sculpture

2.6 building models of things

2.1 drawing

2.6 fixing things that are broken

2.0 playing Dungeons and Dragons

2.0 playing a musical instrument

2.4 building or sewing something from a pattern

1.7 having a collection of something as a hobby

2.6 writing stories

1.8 speaking a foreign language

1.8 grocery shopping for the family

1.7 baby-sitting

2.9 programming a computer

1.6 saving money

1.8 deciding what to do with free time

2.7 doing science experiments at home

2.6 composing music

2.2 doing geometry problems

1.9 discussing politics with parents

2.9 debating on a debate team

0.9 watching science fiction movies or TV shows

1.4 taking family trips

1.3 reading mysteries

2.2 carpentry

1.4 playing computer games

1.4 dancing

1.2 taking trips to COSI, the zoo, art museum

If there are other activities which you feel might be contributions to logical thinking skills, please list them on the back.

Thanks for your help!

## RATING SHEET FOR ITEMS WITHIN THE COGNITIVE AND RECREATIONAL ACTIVITY SCALE

# APPENDIX B

# COGNITIVE AND RECREATIONAL ACTIVITY SCALE

## COGNITIVE AND RECREATIONAL ACTIVITY SCALE

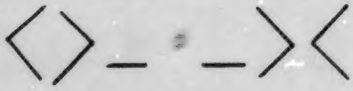
The following is a list of activities in which you may have taken part. Indicate how often you have engaged in each activity by marking the appropriate column.

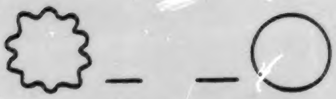
| | Seldom or Never | Occasionally | Often |
|---|---|---|---|
| 1. doing sculpture | ____ | ____ | ____ |
| 2. solving word problems in math | ____ | ____ | ____ |
| 3. building models of things | ____ | ____ | ____ |
| 4. drawing | ____ | ____ | ____ |
| 5. fixing things that are broken | ____ | ____ | ____ |
| 6. playing Dungeons and Dragons | ____ | ____ | ____ |
| 7. playing a musical instrument | ____ | ____ | ____ |
| 8. writing poetry | ____ | ____ | ____ |
| 9. building or sewing something from a pattern | ____ | ____ | ____ |
| 10. writing stories | ____ | ____ | ____ |
| 11. programming a computer | ____ | ____ | ____ |
| 12. doing science experiments at home | ____ | ____ | ____ |
| 13. composing music | ____ | ____ | ____ |
| 14. doing geometry problems | ____ | ____ | ____ |
| 15. debating on a debate team | ____ | ____ | ____ |
| 16. doing carpentry | ____ | ____ | ____ |

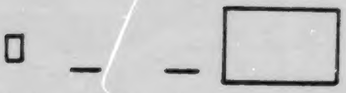
# APPENDIX C

# BRESKIN'S RIGIDITY TEST

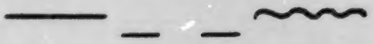
# BRESKIN'S RIGIDITY TEST

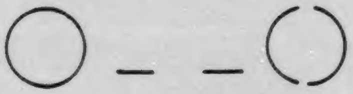
1. 

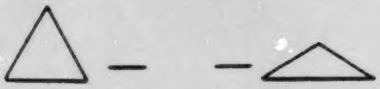
2. 

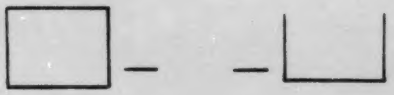
3. 

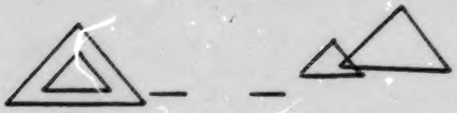
4. 2+3=4 _ _ 1+3=4

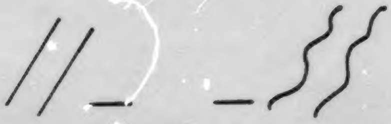
5. 

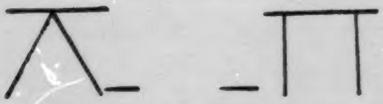
6. 

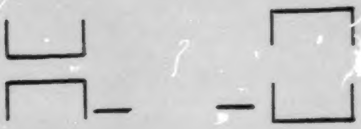
7. 

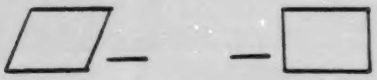
8. 

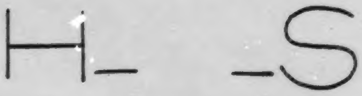
9. 

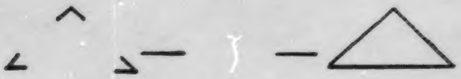
10. 

11. 

12. 

13. 

14. 

15. 

# APPENDIX D

# INTELLECTUAL AND ACADEMIC RESPONSIBILITY QUESTIONNAIRE

## INTELLECTUAL AND ACADEMIC RESPONSIBILITY QUESTIONNAIRE

1. If a teacher passes you to the next grade, would it probably be:

___ a. because she likes you, or
___ b. because of the work you did?

2. When you do well on a test at school, is it more likely to be

___ a. because you studied for it, or
___ b. because the test was especially easy?

3. When you have trouble understanding something at school, is it usually

___ a. because the teacher didn't explain it clearly, or
___ b. because you didn't listen carefully?

4. When you read a story and can't remember much of it, is it usually

___ a. because the story wasn't well written, or
___ b. because you weren't interested in the story?

5. Suppose your parents say you are doing well in school. Is this likely to happen

___ a. because your school work is good, or
___ b. because they are in a good mood?

6. Suppose you did better than usual in a subject at school. Would it probably happen

___ a. because you tried harder, or
___ b. because someone helped you?

7. When you lose at a game or cards or checkers, does it usually happen

___ a. because the other player is good at the game, or
___ b. because you don't play well?

8. Suppose a person doesn't think you are very bright or clever

___ a. can you make him change his mind if you try to, or
___ b. are there some people who will think you're not very bright no matter what you do?

9. If you solve a puzzle quickly, is it

___ a. because it wasn't a very hard puzzle, or
___ b. because you worked on it carefully?

10. If a boy or girl tells you that you are dumb, it is more likely that they sat that

___ a. because they are mad at you, or
___ b. because what you did really wasn't very bright?

11. Suppose you study to become a teacher, scientist, or doctor and you fail. Do you think this would happen

___ a. because you didn't work hard enough, or
___ b. because you needed some help, and other people didn't give it to you?

12. When you learn something quickly in school, is it usually

___ a. because you paid close attention, or
___ b. because the teacher explained it clearly?

13. If a teacher says to you, "Your work is fine," is it

___ a. something teachers usually say to encourage pupils, or
___ b. because you did a good job?

14. When you find it hard to work arithmetic or math problems at school, is it

___ a. because you didn't study well enough before you tried them, or
___ b. because the teacher gave problems that were too hard?

15. When you forgot something you heard in class, is it

___ a. because the teacher didn't explain it very well, or
___ b. because you didn't try very hard to remember?

16. Suppose you weren't sure about the answer to a question your teacher asked you, but your answers turned out to be right. Is it likely to happen

___ a. because she wasn't as particular as usual, or
___ b. because you gave the best answer you could think of?

17. When you read a story and remember most of it, is it usually

___ a. because you were interested in the story, or
___ b. because the story was well written?

18. If your parents tell you that you're acting silly and not thinking clearly, is it more likely to be

___ a. because of something you did, or
___ b. because they happen to be feeling cranky?

19. When you don't do well on a test at school, is it

___ a. because the test was especially hard, or
___ b. because you didn't study for it?

20. If people think you're bright or clever, is it

___ a. because they happen to like you, or
___ b. because you usually act that way?

21. When you win at a game or cards or checkers, does it happen

___ a. because you play real well, or
___ b. because the other person doesn't play well?

22. If a teacher doesn't pass you to the next grade, would it probably be

___ a. because she "had it in for you," or
___ b. because your school work wasn't good enough?

23. Suppose you don't do well as usual in a subject at school. Would this probably happen

___ a. because you weren't as careful as usual, or
___ b. because somebody bothered you and kept you from working?

IAR - continued

24. If a boy or girl tells you that you are bright, is it usually

___ a. because you thought up a good idea, or
___ b. because they like you?

25. Suppose you became a famous teacher, scientist or doctor. Do you think this would happen

___ a. because other people helped you when you needed it, or
___ b. because you worked very hard?

26. Suppose your parents say you aren't doing well in your school work. Is this likely to happen more

___ a. because your work isn't very good, or
___ b. because they are feeling cranky?

27. Suppose you are showing a friend how to play a game and he has trouble with it. Would that happen

___ a. because he wasn't able to understand how to play, or
___ b. because you couldn't explain it well?

28. When you find it easy to work arithmetic or math problems at school, is it usually

___ a. because the teacher gave you especially easy problems, or
___ b. because you studied your book well before you tried them?

29. When you remember something you heard in class, is it usually

___ a. because you tried hard to remember, or
___ b. because the teacher explained it well?

30. If you can't work a puzzle, is it more likely to happen

___ a. because you are not especially good at working puzzles, or
___ b. because the instructions weren't written clearly enough?

31. If you parents tell you that you are bright or clever, it is more likely

___ a. because they are feeling good, or
___ b. because of something you did?

32. Suppose you are explaining how to play a game to a friend and he learns quickly. Would that happen more often

___ a. because you explained it well, or
___ b. because he was able to understand it?

33. Suppose you're not sure about the answer to a question your teacher asks you and the answer you gives turns out to be wrong. Is it likely to happen

___ a. because she was more particular than usual, or
___ b. because you answered too quickly?

34. If a teacher says to you, "Try to do better," would it be

___ a. because this is something she might say to get pupils to try harder, or
___ b. because your work wasn't as good as usual?

# APPENDIX E

## PROCEDURES AND ANSWER SHEET FOR THE SCIENTIFIC REASONING TEST

## Testing Procedures For

## SCIENTIFIC REASONING TEST

Example Question: "The Balancing Beam"

Materials:
1 balance beam
2 10-unit weights

Directions: Show the students the balance beam and the two 10-unit hanging weights. Point out the equally spaced marks along the length of the beam and how the beam balances like a teeter-totter when no weights are hung on it. Hang a 10-unit weight on one side of the beam at mark 7.

Ask the Question:

Where should the other 10-unit weight be hung to make the beam balance?

Question 1: "Geranium and Light"

Materials:
1 large geranium plant with several leaves
covered with aluminum foil
a table lamp

Directions: Explain to the students that you want to do an experiment to see whether light affects the ability of leaves of a plant to produce food. Tell them that a starch test of a leaf indicates whether food has been made. Tell them also that the experiment is designed to test the following rule, and ask students to read the rule along with you as it appears on their answer sheet:

> If the leaves of a plant are kept in the light, then there will be starch in the leaves.

Now explain to the students that you want to find out whether this rule is true or false.

Ask This question:

On your answer sheet are three possible outcomes of an experiment in which leaves are covered or uncovered, and left in the light or dark. Mark which of the three

SCIENTIFIC REASONING TEST -- continued

discoveries would prove the rule above false. (Then ask them to explain their choice or choices in the space provided.)

Question 2: "Fat Rats and Lipids"

Materials:

2 cards labeled "Fat Rat" and "Skinny Rat" with pictures of a fat and a skinny rat
2 cards labeled "High Lipid" and "Low Lipid" with pictures of food dishes

Directions: Using the cards, explain the problem below. Then ask students to respond to the questions on their answer sheets and write why they made their choice or choices.

Ask This Question:

Suppose you are trying to find out why some rats are becoming fat. A friend thinks they are becoming fat because of lipids in their food. Assuming the friend is correct, which of the three situations written on your answer sheet would you expect to occur?

Question 3: "Glass Cylinders One"

Materials:

1 narrow graduated cylinder
1 wide graduated cylinder

Directions: Explain that a given quantity of water rises 4 units in the wide container and 6 units in the narrow one.

Ask This Question:

If we put 6 units of water in the wide cylinder, how high will it rise in the narrow cylinder?

Question 4: "Glass Cylinders Two"

Materials: the same as for Question 3

Directions: Explain that, as in Question Three, a given quantity of water rises 4 units in the wide container and 6 units in the narrow container. Pour water into the narrow cylinder to the 11-units mark.

SCIENTIFIC REASONING TEST -- continued

Ask This Question:

We have just poured eleven units of water into the narrow cylinder. How many units will that fill in the wide cylinder?

Question 5: "The Pendulum's Length"

Materials: 3 pendulums attached to a double ring stand with a bar attached to the stand:

2 pendulums of equal length, one with a 50 and one with a 100 gram weight

1 pendulum longer than the other two, with a 50 gram weight

Directions: Show the students the pendulums attached to the ring stand.

Ask This Question:

Select which of the pendulums would be used in an experiment to find out if the variable of length affects the period (swings per minute) of the pendulum.

Question 6: "The Pendulum's Weight"

Materials: same as for Question 5

Directions: same as for Question 5

Ask This Question:

Suppose you wanted to do an experiment to find out if changing the weight on the end of the string changed the amount of time the pendulum takes to swing back and forth. Which pendulum or pendulums would you use for the experiment?

Question 7: "The Balancing Beam One"

Materials: 1 balance beam
1 10-unit hanging weight
1 5-unit hanging weight

SCIENTIFIC REASONING TEST -- continued

Directions: Show the students the balance beam and the two hanging weights. Hang the 10-unit weight 7 marks out from the fulcrum on the one side of the beam. Point out that the 10 unit weight is hanging at 7 marks from the center.

Ask This Question:

Where would you hang the 5-unit weight to make the beam balance?

Question 8: "The Balancing Beam Two"

Materials:
1 balance beam
1 15-unit weight
1 10-unit weight

Directions: Show the students the balance beam and the two hanging weights. Hang the 15-unit weight 4 marks out from the fulcrum on the one side of the beam. Point out that the 15-unit weight is hanging at 4 marks from the center.

Ask This Question:

Where would you hang the 10-unit weight to make the beam balance?

Question 9: "The Spheres One"

Materials:
1 ramp
1 target sphere
1 heavy sphere
1 light sphere

Directions: Show the ramp to the students. Point out that there are three spheres. One sphere is called the target sphere because it sits at the bottom of the ramp and gets hit by the other spheres that are rolled down the ramp. The other spheres (a heavy and a light one) are rolled from one of two positions: a low position half-way up the ramp or a high position at the top of the ramp.

Point out the low and high positions on the ramp and demonstrate how the spheres roll down the ramp, hit the target sphere, and cause it to move a certain measurable distance up the other side of the ramp.

Tell the students that you will describe one half of an experiment with the spheres and the ramp and that they will have to tell you how to complete the experiment. Have the students imagine an experiment in which the light sphere was released from the low position, rolled down the ramp, hit and propelled the target sphere up the other side of the ramp.

Ask This Question:

Which of the spheres would you now release from the high position to find out if the place from which a sphere is released makes a difference in how far the target goes?

Question 10: "The Spheres Two"

Materials:
1 ramp
1 light target sphere
1 heavy target sphere
1 sphere called Metal A
1 sphere called Metal B

Directions: Point out the light and heavy target spheres and Metal A and Metal B. Tell the students that you will demonstrate an experiment and then ask them a question about the experiment.

Place the heavy target sphere at the bottom of the ramp. Hold Metal A at the high position on the ramp. Tell the students to imagine that Metal A rolls down the ramp and hits the heavy target and that the target moves a certain distance up the other side of the ramp (do not actually release Metal A). Now place the light target sphere at the bottom of the ramp. Hold Metal B at the high position on the ramp. Point out that this is the same position from which Metal A was released. Tell the students to imagine that Metal B rolls down the ramp and hits the light target and that the target moves a certain distance up the other side of the ramp (do not actually release Metal B).

Tell the students that when this experiment was actually done, Metal B hit its target farther than Metal A hit its target.

Ask This Question:

Does this experiment prove that Metal B can hit a target farther than Metal A can?

Note: Do not tell the students anything about the relative weights of Metal A and B.

Question 11: "The Metal Box"

Materials: 1 metal box with four switches, a black button, and a light bulb on it

Directions: Point out the box, the switches, the light bulb and the black button. Point out that the switches are identified by four colors so that there is a "yellow switch," a "blue switch," a "red switch," and a "green switch." The switches can be flipped into either an "up position" or a "down position." If the correct switch or switches are flipped into the up position, and the black button is pushed, the bulb will light.

Cover the switches and flip the blue and green switches into the up position. Push the button to show the students that the bulb will, in fact, light if the correct switch or switches are flipped. You may need to flip other switches up and down again to assure that the students are not clued as to the correct combination. Flip all switches back to the down position and uncover them.

Explain that the objective of this puzzle is to discover which switch or switches must be flipped to make the light turn on. To do this they would actually need to use the box, but since there is only one box, they can only indicate how they would go about flipping switches to find out.

Show them how to use the symbols y, b, r, g, and the spaces labeled "Your Record" on their booklets by doing the example. Flip switch y (the yellow switch), push the black button, and note that the light remains off.

Explain that on each try the order in which the switches are flipped does not matter. For instance, y,r and r,y are the same trial so they should not write both down.

Question 12: "The Shopping Center"

Materials: 4 pictures of stores:
Barber Shop (B)
Discount Store (D)
Grocery Store (G)
Coffee Shop (C)

Directions: Read the problem out loud. Show the students the 4 stores. Arrange them in the following way: B D G C. Show them that this order corresponds to that indicated on the first line in the booklet. This means that the Barber Shop is in the first store location on the left, the Discount Store is in the second store location, the Grocery Store is in the third store location, and the Coffee Shop is in the fourth store location on the right.

Ask This Question:

Now write all other possible ways that the stores could be arranged, one arrangement per line. Note that there are extra lines in your booklet.

Question 13: "The Squares"

Materials:
1 cloth sack
3 yellow wooden squares
3 red wooden squares

Directions: Show the students the sack and the 3 yellow and 3 red wooden squares. Point out that each square is identical in size and shape.

Place all the squares into the sack. Shake them up. Reach into the sack and select one piece (the first that you touch). Have the students imagine that you are going to pull this piece out of the sack.

Ask This Question:

What are the chances of pulling out a red square on the first try?

**Question 14**: "Squares and Diamonds 1"

Materials:

1 cloth sack
3 red wooden squares
4 yellow wooden squares
5 blue wooden squares
4 red wooden diamonds
2 yellow wooden diamonds
3 blue wooden diamonds

Directions: Show the students the cloth sack and the square and diamond shaped pieces. Point out that all of the square shaped pieces are identical in size and shape as are the diamond shaped pieces. Place all of the pieces into the sack. Shake them up. Reach into the sack and select one piece (the first that you touch). Have the students imagine that you are going to pull this piece out of the sack.

Ask This Question:

What are the chances of pulling out a red piece on the first try?

**Question 15**: "Squares and Diamonds 2"

Materials: same as for Question 14

Directions: Shake up the pieces once again. Reach in and select one piece (the first one that you touch). Have the students imagine that you are going to pull this piece out of the sack.

SCIENTIFIC REASONING TEST -- continued

Ask This Question:

> What are the chances of pulling out a red diamond or a blue diamond on the first try?

Note: The Example Question and Questions 3 through 15 were adapted from the *Classroom Test of Formal Operations: Testing and Scoring Procedures and Answer Key*. Mimeo. Available from A. E. Lawson, Science Education, Department of Physics, Arizona State University, Tempe, Arizona 85281.

## Answer Sheet for

## SCIENTIFIC REASONING TEST

**DIRECTIONS**: For each of the items below a situation will be demonstrated. Each demonstration will lead to a question or questions for which there are a number of possible answers. For each item you are to check the box of the best answer and explain your choice in the space provided.

**Example Item**: "The Balancing Beam"

☐ Mark 3 ☐ Mark 7 ☐ Mark 8 ☐ Mark 10

Please explain your choice:

**Item 1:** "Geranium and Light"

This is the rule: IF THE LEAVES OF A PLANT ARE KEPT IN THE LIGHT, THEN THERE WILL BE STARCH IN THE LEAVES.

Mark which one of the possible discoveries listed below would prove the rule to be false.

☐ Leaves kept in the light do have starch.

☐ Leaves covered with the foil do have starch.

☐ Leaves covered with the foil do not have starch.

Please explain your choice:

SCIENTIFIC REASONING TEST - continued

Item 2: "Fat Rats and Lipids"

Suppose you are trying to find out why some rats are becoming fat. A friend thinks they are becoming fat because of lipids in their food. Assuming the friend is correct, which of these situations would you expect to occur?

☐ The rats stop eating the food with lipids and they become fatter.

☐ The rats continue eating the food with lipids and they become thinner.

☐ The rats stop eating the food with lipids and they become thinner.

Please explain your choice:

Item 3: "Plastic Cylinders 1"

The water will rise to which Mark?

☐ 7 ☐ 8 ☐ 9 ☐ 10

☐ Other ☐ There is no way of predicting.

Please explain your choice:

Item 4: "Plastic Cylinders 2"

The water will rise to Mark:

☐ 5 1/3 ☐ 5 2/3 ☐ 7 1/3 ☐ 7 1/2 ☐ 8

☐ 8 1/3 ☐ 8 1/2 ☐ 9 ☐ Other

☐ No way of predicting.

Please explain your choice:

SCIENTIFIC REASONING TEST - continued

Item 5: "The Pendulum's Length"

Which pendulum or pendulums would you use for the experiment?

☐ 1 and 2 ☐ 1 and 3 ☐ 2 and 3

☐ 1, 2 and 3 ☐ 2 only

Please explain your choice:

Item 6: "The Pendulum's Weight"

Which pendulum or pendulums would you use for the experiment?

☐ 1 and 2 ☐ 1 and 3 ☐ 2 and 3 ☐ 3 only

Please explain your choice:

Item 7: "The Balancing Beam 1"

Where would you hang the 5-unit weight to make the beam balance?

☐ between Mark 3 and 4 ☐ Mark 7 ☐ Mark 12

☐ Mark 14 ☐ At the end

Please explain your choice:

SCIENTIFIC REASONING TEST - continued

**Item 8**: "The Balancing Beam 2"

Where would you hang the 10-unit weight to make the beam balance?

☐ Mark 5 ☐ Mark 6 ☐ between Mark 6 and 7

☐ Mark 7 ☐ Mark 8 ☐ Mark 9

☐ Mark 10 ☐ Mark 17

Please explain your choice:

**Item 9**: "The Spheres 1"

Which sphere would you release from the high position to find out if the place a sphere is released makes a different in how far the target goes?

☐ the heavy sphere ☐ the light sphere

Please explain your choice:

**Item 10**: "The Spheres 2"

Does this experiment prove that Metal B can hit a target farther than Metal A can?

☐ yes ☐ no ☐ need more information

Please explain your choice:

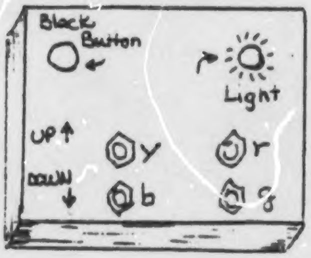
SCIENTIFIC REASONING TEST - continued

Item 11: "The Metal Box"

The objective of this puzzle is to discover which switch or switches must be flipped to make the light turn on.

Example:

| | ON | OFF |
|---|---|---|
| 1. y | | ✓ |



y - yellow switch

b - blue switch

r - red switch

g - green switch

Your record:

1. 
2. 
3. 
4. 
5. 
6. 
7. 
8. 
9. 
10. 
11. 
12. 
13. 
14. 
15. 
16. 
17. 
18. 
19. 
20. 
21. 
22. 
23. 
24. 
25. 
26. 
27. 
28. 
29. 
30.

SCIENTIFIC REASONING TEST - continued

**Item 12:** "The Shopping Center"

In a new SHOPPING CENTER, 4 store locations are going to be opened on the ground level.

A BARBER SHOP, a DISCOUNT STORE, a GROCERY STORE, and a COFFEE SHOP want to move there. Each one of the stores can choose any one of the 4 locations. Write ALL THE POSSIBLE WAYS that the stores can occupy the 4 locations. Write on the lines below the letter B for BARBER SHOP, the letter D for DISCOUNT STORE, the letter G for GROCERY STORE, and the letter C for COFFEE SHOP.

BDGC ______ ______
______ ______ ______
______ ______ ______
______ ______ ______
______ ______ ______
______ ______ ______
______ ______ ______
______ ______ ______
______ ______ ______
______ ______ ______

**Item 13:** "The Squares"

Three yellow squares and three red squares are put into a sack. What are the chances of pulling out a red square on the first try?

☐ 1 out of 1
☐ 1 out of 2
☐ 1 out of 3
☐ 1 out of 6
☐ 2 out of 6
☐ 4 out of 6
☐ 3 out of 3
☐ other

Please explain your choice.

SCIENTIFIC REASONING TEST - continued

Item 14: "Squares and Diamonds 1"

Three red squares, four yellow squares, and five blue squares are put into a sack. Four red diamonds, two yellow diamonds, and three blue diamonds are put into the same sack. What are the changes of pulling out a red piece on the first try?

☐ 1 out of 1

☐ 1 out of 2

☐ 1 out of 3

☐ 1 out of 4

☐ 1 out of 21

☐ 7 out of 21

☐ 1 out of 7

☐ other

Please explain your choice:

Item 15: "Squares and Diamonds 2"

Three red squares, your yellow squares, and five blue squares are put into a sack. Four red diamonds, two yellow diamonds, and three blue diamonds are put into the same sack. What are the changes of pulling out a red diamond or a blue diamond on the first try?

☐ 1 out of 1

☐ 1 out of 2

☐ 1 out of 3

☐ 1 out of 4

☐ 8 out of 21

☐ 9 out of 21

☐ other

Please explain your choice:

# BIBLIOGRAPHY

Adi, H., and Pulos, S. Individual differences and formal operational performance of college students. Journal of Research in Math Education, 1980, 11, 150-156.

Archer, J., and Lloyd, B. Sex and Gender. New York: Penguin Books, 1982.

Asher, H. B. Causal Modeling. Sage University Paper series on Quantitative Applications in the Social Sciences, 07-001. Beverly Hills, California: Sage Publications, 1976.

Barrett, W. Irrational Man. A Study in Existential Philosophy. Garden City, New York: Doubleday and Co., 1962.

Bender, D. S., and Milakofsky, L. College chemistry and Piaget: The relationship of aptitude and achievement measures. Journal of Research in Science Teaching, 1982, 19, 205-216.

Block, J. Assimilation, accommodation, and the dynamics of personality development. Child Development, 1982, 53, 281-295.

Blosser, P. A critical review of the role of the laboratory in science teaching. Columbus, Ohio: ERIC Clearinghouse for Science, Mathematics, and Environmental Education, 1981.

Brainerd, C. J. Piaget's Theory of Intelligence. Englewood Cliffs, New Jersey: Prentice-Hall, 1978.

Breskin, S. Measurement of rigidity, a non-verbal test. Perceptual and Motor Skills, 1968, 27, 1203-1206.

Breskin, S. Extension of norms for the Breskin Rigidity Test (BRT). I. Elementary school children. Perceptual and Motor Skills, 1969, 28, 826.

Breskin, S., and Gorman, B. S. On rigidity and field-dependence. *Perceptual and Motor Skills*, 1969, *29*, 541-542.

Breskin, S., and Rich, K. D. Correlation of non-verbal rigidity and intelligence in elementary school children. *Perceptual and Motor Skills*, 1971, *32*, 194.

Brinkmann, E. H. Programmed instruction as a technique for improving spatial visualization. *Journal of Applied Psychology*, 1966, *50*, 179-184.

Bronowski, J. *The Common Sense of Science*. New York: Vintage Books, 1951.

Bybee, R. W., and Sund, R. B. *Piaget For Educators* (2nd ed.). Columbus, Ohio: Charles E. Merrill, 1982.

Campbell, D. T., and Stanley, J. C. *Experimental and Quasi-Experimental Designs for Research*. Chicago: Rand, McNally and Company, 1963.

Carpenter, T. P. Research in cognitive development. Chapter VII. In R. J. Shumway (Ed.), *Research in Mathematics Education*. Reston, Virginia: National Council of Teachers of Mathematics, 1980.

Case, R. Gearing the demands of instruction to the developmental capacities of the learner. *Review of Educational Research*, 1975, *45*, 59-87.

Case, R. Intellectual development and instruction: A neo-Piagetian view. In A. E. Lawson (Ed.), *1980 AETS Yearbook: The Psychology of Teaching for Thinking and Creativity*. Columbus, Ohio: ERIC Clearinghouse for Science, Mathematics, and Environmental Education, 1979.

Cloutier, R., and Goldschmid, M. L. 1976. Individual differences in the development of formal reasoning: *Child Development*, 1976, *47*, 1097-1102.

Cohen, M. R. *Reason and Nature. An Essay on the Meaning of Scientific Method*. Glencoe, Illinois: The Free Press Publishers, 1953.

Cooke, D., and Campbell, D. T. *Quasi-Experimentation: Design and Analysis Issues for Field Settings*. Chicago: Rand McNally College Publishing Co., 1979.

Crandall, V. C., Katkovsky, W., and Crandall, V. J. Children's beliefs in their control of reinforcement in intellectual academic achievement behaviors. _Child Development_, 1965, _36_, 91-109.

Crandall, V. C., and Lacey, B. W. Children's perceptions of internal-external control in intellectual-academic situations and their Embedded Figures Test performance. _Child Development_, 1972, _43_, 1123-1134.

Crandall, V. J., Katkovsky, W., and Preston, A. Motivational and ability determinants of young children's intellectual academic achievement situations. _Child Development_, 1962, _33_, 643-661.

Crandall, V. J., and Sinkeldam, C. Children's dependent and achievement behaviors in social situations and their perceptual field dependence. _Journal of Personality_, 1964, _32_, 1-22.

Cronbach, L. J., and Snow, R. E. _Aptitudes and Instructional Methods_. New York: Irvington Publishers, 1977.

Das, J. P., J. R. Kirby, and Jarman, R. F. _Simultaneous and Successive Cognitive Processes_. New York: Academic Press, 1979.

DeCarlo, T. J. Recreation participation patterns and successful ageing. _Journal of Gerontology_, 1974, _29_, 416-422.

DeRussy, E. A., and Futch, E. Field dependence-independence as related to college curricula. _Perceptual and Motor Skills_, 1971, _33_, 1235-1237.

DeVries, R. Relationships among Piagetian, IQ, and achievement assessment. _Child Development_, 1974, _45_, 746-756.

Dewey, J. _Democracy and Education: An Introduction to the Philosophy of Education_. New York: The MacMillan Co., 1916.

Educational Policies Commission. [_The Central Purpose of American Education_]. In A. E. Lawson (Ed.), _1980 AETS Yearbook: The Psychology of Teaching for Thinking and Creativity_. Columbus, Ohio: ERIC Clearinghouse for Science, Mathematics, and Enviromental Education, 1979. (Reprinted from Washington, D. C., 1961).

Educational Policies Commission. _Education and the Spirit of Science_. Washington, D. C., 1966.

Elkind, D. Quantity conceptions in college students. Journal of Social Psychology, 1962, 57, 459-465.

Epstein, H. T. Phrenoblysis: Special brain and mind growth periods. I. Human brain and skull development. Developmental Psychobiology, 1974, 7, 207-216. (a)

Epstein, H. T. Phrenoblysis: Special brain and mind growth periods. II. Human mental development. Developmental Psychobiology, 1974, 7, 217-224. (b)

Farnsworth, C. Using an intensive time-series design to develop profiles of daily achievement and attitudes of eighth grade earth science students at different cognitive levels during the study of plate tectonics. Unpublished Ph.D. dissertation, Ohio State University, 1981.

Fazio, R., and Zambotti, G. Some cognitive style variables and their relationship to chemical achievement. Journal of College Science Teaching, 1977, 6, 154-155.

Feather, N. T. Some personality correlates of external control. Australian Journal of Psychology, 1967, 19, 253-260.

Fennema, E., and Sherman, J. Sex-related differences in mathematics achievement, spatial visualization and affective factors. American Educational Research Journal, 1977, 14, 51-71.

Flavell, J. H. Cognitive Development. Englewood Cliffs, New Jersey: Prentice Hall, 1977.

Flavell, J. H. On cognitive development. Child Development, 1982, 53, 1-10.

Fox, D. J. The Research Process in Education. Chicago: Holt, Rinehart and Winston, Inc., 1969.

Frenkel-Brunswik, E. Intolerance of ambiguity as an emotional and perceptual personality variable. Journal of Personality, 1949, 18, 108-143.

Gabel, D. L. Piagetian research as applied to teaching science to secondary and college students. Viewpoints in Teaching and Learning, 1979, 55, 24-33.

Gardner, R. W, Holzman, P. S., Klein, G. S., Linton, H. B., and Spence, D. P. Cognitive control: a study of individual consistencies in cognitive behavior. Psychological Issues, 1959, 4(1, Whole No. 4).

Goldstein, K. M., and Blackman, S. Cognitive Style: Five Approaches and Relevant Research. New York: John Wiley and Sons, 1978.

Guilford, J. P., and Fruchter, B. Fundamental Statistics in Psychology and Education. St. Louis: McGraw-Hill Book Co., 1978.

Harbeck, M. B. (Ed.). 2nd Sourcebook for Science Supervisors. Washington, D.C.: National Science Supervisors Association, 1976.

Harms, N. C., and Yager, R. E. What Research Says To the Science Teacher (Vol. 3). Columbus, Ohio: ERIC Clearinghouse for Science, Mathematics and Environmental Education, 1980.

Hull, C. H., and Nie, N. H. SPSS Update: New Procedures and Facilities for Releases 7 and 8. St. Louis: McGraw-Hill Book Co., 1979.

Inhelder, B., and Piaget, J. [The Growth of Logical Thinking from Childhood to Adolescence.] (A. Parsons and S. Milgram, Trans.). New York: Basic Books, Inc., 1958.

Kahle, J. B. The disadvantaged majority: science education for women. AETS Outstanding Paper for 1983. Burlington, North Carolina: Carolina Biological Supply Co., 1983.

Kamii, C. Pedagogical principles from Piaget's theory. In M. Schwebel and J. Raph (Eds.), Piaget in the Classroom. New York: Basic Books, Inc., 1973.

Karplus, R. Teaching for the development of reasoning. In A. E. Lawson (Ed.), The Psychology of Teaching for Thinking and Creativity. Columbus, Ohio: ERIC Clearinghouse for Science, Mathematics, and Environmental Education, 1979.

Keating, D. P. Precocious cognitive development at the level of formal operations. Child Development, 1975, 46, 276-280.

Kuhn, D. The application of Piaget's theory of cognitive development to education. Harvard Educational Review, 1979, 49, 340-360.

Lawson, A. E. Formal operations and field independence in a heterogeneous sample. Perceptual and Motor Skills, 1976, 42, 981-982.

Lawson, A. E. The development and validation of a classroom test of formal reasoning. Journal of Research in Science Teaching, 1978, 15, 11-24.

Lawson, A. E. Combining variables, controlling variables, and proportions: Is there a psychological link? Science Education, 1979, 63, 67-72.

Lawson, A. E. The nature of advanced reasoning and science instruction. Journal of Research in Science Teaching, 1982, 19, 743-760.

Lawson, A. E., and Renner, J. W. A quantitative analysis of responses to Piagetian tasks and its implications for curriculum. Science Education, 1974, 58, 454-559.

Lawson, A. E., and Renner, J. W. Piagetian theory and biology teaching. American Biology Teacher, 1975, 37, 336-343.

Lawson, A. E., and Wollman, W. T. Cognitive level, cognitive style, and value judgment. Science Education, 1977, 61, 397-408.

Lefcourt, H. M. Locus of Control: Current Trends in Theory and Research (2nd ed.). Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1982.

Lefcourt, H. M., and Telegdi, M. S. Perceived locus of control and field dependence as predictors of cognitive activity. Journal of Consulting and Clinical Psychology, 1971, 37, 53-56.

Levine, D., and Linn, M. Scientific reasoning ability in adolescence: Theoretical viewpoints and educational implications. Journal of Research in Science Teaching, 1977, 14, 371-384.

Linn, M. C., Pulos, S., and Gans, A. Correlates of formal reasoning: Content and problem effects. Journal of Research in Science Teaching, 1981, 18, 435-447.

Linn, M., and Swiney, J. F. Individual differences in formal thought: Role of expectations and aptitudes. *Journal of Educational Psychology*, 1981, *73*, 274-286.

Lowery, L. F. Toward improving the science education research enterprise. *Journal of Research in Science Teaching*, 1980, *17*, 275-282.

Maccoby, E. E., and Jacklin, C. N. *Psychology of Sex Differences*. Stanford, California: Stanford University Press, 1974.

Mallon, E. J. Cognitive development and processes: Review of the philosophy of Jean Piaget. *American Biology Teacher*, 1976, *38*, 28-33.

Marx, M. H., and Hillix, W. A. *Systems and Theory in Psychology* (3rd ed.). St. Louis: McGraw-Hill, 1979.

Maslow, A. H. *Toward a Psychology of Being*. Princeton, New Jersey: D. Van Nostrand Co., 1962.

McCrary, K. J., and Long, H. B. The role of environmental stimulation in adult cognitive functioning. *Journal of Research and Development in Education*, 1980, *13*, 33-43.

McKinnon, J. W., and Renner, J. W. Are colleges concerned with intellectual development? *American Journal of Physics*, 1971, *39*, 1047-1052.

Messer, S. B. Reflection-impulsivity: A review. *Psychological Bulletin*, 1976, *83*, 1026-1052.

Mooney, R. L. *A set of left-brain propositions to accompany a right-brain production*. Mimeo. Columbus, Ohio: The Ohio State University, 1979.

Mooney, R. L. *Research Papers: The Phenomenon of Mind, Vol. II of a Series of Volumes. Selected Writings*. Mimeo. Columbus, Ohio: The Ohio State University, 1980.

Moonie, N., and Versey, J. Breskin test of rigidity and restriction of attention. *Perceptual and Motor Skills*, 1977, *44*, 844.

Nagy, P., and Griffith, K. A. Limitations of research relating Piaget's theory to adolescent thought. *Review of Educational Research*, 1982, *52*, 513-556.

Nie, N. H., Hull, C. H., Jenkins, J. G., Steinbrenner, K., and Bent, D. H. *Statistics Package for the Social Sciences* (2nd ed.). St. Louis: McGraw-Hill, 1975.

Niemark, E. D. Current status of formal operations research. Human Development, 1979, 22, 60-67.

Padilla, M. J., Okey, J. R., and Dillashaw, F. G. The relationship between science process skill and formal thinking abilities. Journal of Research in Science Teaching, 1983, 20, 239-246.

Pascual-Leone, J. A mathematical model for the transition rule in Piaget's developmental stages. Acta Psychologica, 1970, 32, 301-345.

Pedhazur, E. J. Multiple Regression in Behavioral Research: Explanation and Prediction (2nd ed.). Chicage: Holt, Rinehart and Winston, 1982.

Peel, E. A. The Nature of Adolescent Judgment. London Press: London, 1971.

Petersen, A. C., and Wittig, M. A. Differential cognitive development in adolescent girls. In M. Sugar (Ed.), Female Adolescent Development. New York: Brunner/Mazel, 1979.

Phares, E. J. Locus of Control in Personality. Morristown, New Jersey: General Learning Press, 1976.

Phillips, J. L., Jr. The Origins of Intellect: Piaget's Theory (2nd ed.). San Francisco: W. H. Freeman and Co., 1975.

Piaget, J. Development and learning. Journal of Research in Science Teaching, 1964, 2, 176-186.

Piaget, J. Intellectual evolution from adolescence to adulthood. Human Development, 1972, 15, 1-12.

Piaget, J. [The Child and Reality.] (A. Rosin, Trans.). New York: Grossman Publishers, 1973.

Renzulli, J. S. The Interest-A-Lyzer. Wethersfield, Connecticutt: Creative Learning Press, 1977.

Rogers, C. R. On Becoming A Person. Boston: Houghton Mifflin Co., 1961.

Rokeach, M. The Open and Closed Mind. New York: Basic Books, 1960.

Rotter, J. B. Generalized expectancies for internal versus external control of reinforcement. Psychological Monographs, 1966, 80 (1, Whole No. 609).

Rowe, M. B. Relation of wait-time and rewards to the development of language, logic, and fate control: Part II -- rewards. *Journal of Research in Science Teaching*, 1974, *11*, 291-308.

Rowell, J. A., and Hoffmann, P. J. Group tests for distinguishing formal from concrete thinkers. *Journal of Research in Science Teaching*, 1975, *12*, 157-164.

Rychlak, J. F. *Introduction to Personality and Psychotherapy: A Theory-Construction Approach*. Geneva, Illinois: Houghton Mifflin Co., 1981.

Schwebel, M. Formal operations in first-year college students. *Journal of Psychology*, 1975, *91*, 133-141.

Shayer, M., and Adey, P. *Towards A Science of Science Teaching: Cognitive Development and Curriculum Demand*. London: Heinemann Educational Books, 1981.

Sherman, J. Problems of sex differences in space perception and aspects of intellectual functioning. *Psychological Review*, 1967, *74*, 290-299.

*Short Form Test of Academic Aptitude* (Examiner's Manual). Monterrey, California: CTB/McGraw Hill, 1970.

Showalter, V., Cox, D., and Holobinko, P. What is Unified Science education. V. Program objectives and scientific literacy. *Prism II*, 1974 *2*(*3* and*4*).

Sugar, M. (Ed.). *Female Adolescent Development*. New York: Brunner/Macel, 1979.

Taba, H. *Curriculum Development, Theory, and Practice*. Chicago: Harcourt, Brace and World, Inc., 1962.

Tanner, J. M., and Inhelder, B. (Eds.). *Discussion on Child Development*. New York: International Universities Press, 1958.

Thurstone, L. L., and Jeffrey, T. E. *Closure Flexibility* (*Concealed Figures*, Form A). Chicago: Industrial Relations Center, 1956.

Tobin, K., and Capie, W. The development and validation of a group test of logical thinking. *Educational and Psychological Measurement*, 1981, *41*, 413-424.

Towler, J. D., and Wheatley, G. Conservation concepts in college students: A replication and critique. *Journal of Genetic Psychology*, 1971, *118*, 265-270.

Treagust, D. F. Gender-related differences of adolescents in spatial representational thought. *Journal of Research in Science Teaching*, 1980, *17*, 91-97.

Vernon, P. E. The distinctiveness of field independence. *Journal of Personality*, 1972, *40*, 366-391.

Walker, R. A., Mertens, T. R., and Hendrix, J. R. Formal operational reasoning patterns and scholastic achievement in genetics. *Journal of College Science Teaching*, 1979, *8*, 156-158.

Weisz, J. R., O'Neill, P., and O'Neill, P. C. Field dependence-independence on the Children's Embedded Figures Test: Cognitive style or cognitive level? *Developmental Psychology*, 1975, *11*, 539-540.

Welch, W. W. Inquiry in school science. In N. C. Harms and R. E. Yager (Eds.). *What Research Says To The Science Teacher* (Vol. 3). Columbus, Ohio: ERIC Clearinghouse for Science, Mathematics, and Enviromental Education, 1980.

Willoughby, R. H. Field dependence and locus of control. *Perceptual and Motor Skills*, 1967, *24*, 671-672.

Wilson, E. O. *On Human Nature*. Cambridge, Massachusetts: Harvard University Press, 1978.

Witkin, H. A., Moore, C. A., Goodenough, D. R., and Cox, P. W. Field-dependent and field-independent cognitive styles and their educational implications. *Review of Educational Research*, 1977, *47*, 1-64.

Wollman, W., Eylon, B.-S., and Lawson, A. E. An analysis of premature closure in science and developmental stages. *Journal of Research in Science Teaching*, 1980, *17*, 105-114.

Yalom, I. D. *Existential Psychotherapy*. New York: Basic Books, Inc., 1980.